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Le droit et l'information instantanée par la cybernétique

par R. DEGOUY,

Président de Chambre
à la Cour d'Appel de Paris (1)

Lorsque l'on regarde dans une bibliothèque les recueils des lois et décrets depuis le Ier Empire, on constate, rien qu'à l'épaisseur des reliures, que les temps contemporains, depuis trente-cinq ans, se distinguent de ceux qui les précèdent par une abondance inouïe de textes législatifs et réglementaires. Cet état de choses relativement nouveau a comporté bien des conséquences. Une entre autres : il a paru tant et tant de textes chaque jour qu'il était souvent très difficile de reconnaître une loi à sa seule date. Aussi le besoin d'une réforme s'est-il fait sentir. Elle ne survint qu'en 1945.

A vrai dire, elle passa à peu près inaperçue du public. Il s'agissait cependant d'un de ces petits faits significatifs que l'historien aime à retenir. Le gouvernement décida en effet, de numéroter les lois, décrets et ordonnances. Depuis lors, nous voyons chaque texte pourvu d'un matricule, son numéro précédé du millésime de l'année. On entend ainsi parler de la loi N° 58-743 du ... etc...

Les premiers signes inquiétants de cette prolifération législative apparurent pendant l'entre-deux-guerres, juste au moment où surgirent les décrets-lois du ministère Poincaré de 1926. Le recueil Dalloz législatif de cette année-là atteint 1.251 pages, environ le double des années calmes. Or, il s'agit, comme vous savez, de pages

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(1) Texte de la conférence prononcée le 18 juin 1960 à la Première Chambre de la Cour d'Appel de Paris, sous la présidence de M. le Premier Président Rousselet, Membre de l'Institut. L'auteur remercie Me Simone Lévy, avocat au barreau de Montbéliard et M. Louis Couffignal, administrateur de l'Association Internationale de Cybernétique, pour la part si importante qu'ils ont prise à la préparation de ce texte et aux échanges de vue qui ont précédé sa rédaction.

de deux colonnes imprimées en assez petits caractères. En moyenne, il y eut en 1926, trois pages et demie à lire et à s'assimiler par jour en ne s'accordant ni fête, ni vacance. Mais cette surabondance devait être dépassée en 1939 avec 1.594 pages. L'année 1959 dont nous garderons tous souvenir, ne vient qu'en troisième rang avec 1.310 pages, puis l'année 1935 avec 1.236 pages...

Où est-il le temps qu'évoquait, dans ma jeunesse, certaine version grecque qui nous apprenait comment on légiférait chez les Locriens. L'homme qui proposait une loi nouvelle était mis à mort si son texte n'était pas adopté. C'était un moyen de mettre un frein aux propositions faites à la légère. Si des Locriens de cette période archaïque revenaient parmi nous, quel serait leur effroi devant la marée de lois qui menace de nous submerger !

Nous savons, par expérience, les conséquences de ce pullulement de textes et les efforts qu'il faut faire pour apprendre, vingt fois en sa vie, des parties considérables du droit qui précédemment n'avaient pas bougé en plusieurs siècles (1) ! La matière même des lois va en se compliquant progressivement. On se plaint de ces lois qui sont promulguées sans être accompagnées de leurs travaux préparatoires et qui posent des énigmes aux plus ingénieux, On se plaint des lois contenant souvent des articles fort obscurs, des textes interprétatifs, donc rétroactifs, qui s'enchevêtrent, se renvoient les uns aux autres, entraînant des abrogations implicites et quelquefois renversant sans crier gare les principes les mieux établis. Les à-coups d'une évolution accélérée réservent aux juristes, à tous les carrefours du droit, des surprises étonnantes. Exemple : à peine l'édition des codes de 1959 venait-elle de paraître qu'elle était déjà en grande partie périmée. Malgré cela, nul n'étant censé ignorer la loi, professeurs, avocats, avoués, notaires, magistrats sont tenus, plus encore que le commun des mortels, à savoir tout de suite le dernier état de la législation !

Or, aucune publication, même mise à jour périodiquement, ne peut fournir instantanément cet état toujours changeant et toujours provisoire. Il y a une période pendant laquelle il faut se reporter aux derniers numéros du Journal Officiel. Mais combien de praticiens ont le temps et les moyens de tenir fidèlement à jour, *sans retard*, leur documentation pour toutes les questions dont ils

(1) En 1958, dans une période, à vrai dire exceptionnelle, on relève près de 1.470 décrets et presque autant d'ordonnances, ce qui, sans compter les lois votées dans les derniers mois de la IVe République, fait environ *huit* textes nouveaux par jour, dont certains à eux seuls remplissent plusieurs pages du Journal Officiel.

peuvent être saisis ? Même au prix d'un effort considérable, qui a la certitude d'avoir sous la main, *sans omission,* la totalité des textes dont il a besoin ? Il s'en suit trop souvent, à l'occasion de la moindre recherche, un gaspillage de temps et d'énergie, des risques d'erreurs, un sentiment insupportable d'incertitude, facteur certain du scandaleux surmenage intellectuel dont souffrent à présent les gens de robe comme les autres. L'étude des affaires ou l'élaboration des jugements soulève des difficultés pratiques que nos devanciers ignoraient. Les procès les meilleurs peuvent être perdus parce qu'on a invoqué un décret abrogé depuis huit jours. Des décisions risquent d'être rendues en application de textes périmés et remplacés, d'où cassation. Nouvelle perte de temps et d'argent pour tout le monde.

A peine un commentaire a-t-il paru (par ex. sur la prohibition des indexations ou sur le taux des loyers professionnels) qu'une loi nouvelle bouleverse la précédente, mettant à néant l'effort d'assimilation auquel il avait fallu se livrer et obligeant à tout recommencer. Les conventions privées qui reposent sur l'accord des volontés, les prévisions les plus sages, les mieux calculées, se trouvent profondément modifiées dans leurs effets en des matières où la théorie de l'imprévision n'est pas applicable. Le droit devient, en diverses parties (loyer, urbanisme, matières économique, monétaire, fiscale, sécurité sociale), comparable à un chantier en proie à de perpétuels remaniements. Dégager et comprendre les grandes lignes de ces constructions mouvantes pour les rattacher, si faire se peut, aux bases fondamentales de nos principes juridiques, devient un problème ardu réservé à la seule virtuosité de quelques spécialistes.

Les causes multiples de cet état de choses ont été maintes fois dénoncées : l'intervention de l'Etat, le dirigisme, la planification avec l'apparition d'organismes hybrides relevant à la fois du droit privé et du droit administratif, le morcellement du travail législatif, la dispersion des règlementations, un manque de coordination entre les diverses administrations. Tous maux dont notre pays n'a pas le monopole.

A défaut de plan d'ensemble ou par ignorance, le droit commun se voit supplanté et même contredit par des règles généralement fort compliquées en des matières nouvelles qui se sont développées sans tenir compte des principes préexistants, dûment éprouvés par l'usage et auxquels tous sont habitués. Pour ne citer en exemple que les lois et décrets concernant le remembrement ou la sécurité sociale, les praticiens savent combien il leur est difficile — et a

fortiori à « l'homme de la rue » — de se retrouver parmi les textes touffus, embrouillés, usant parfois d'un langage spécial, hermétique aux non initiés, plein d'énigmes, de formules algébriques, encombrés des plus menus détails et qui aboutissent parfois à renverser subrepticement les notions élémentaires et non abrogées du Code Civil sur la propriété ou sur la responsabilité.

Que dire aussi des résultats pratiques de la multiplication des juridictions d'exception, chacune ayant sa procédure (délais, voies de recours, formalisme) ? Quelles complications *inutiles* elles apportent avec leur suite inévitable « d'exceptions d'incompétence [1] », alors qu'il eut été tout simple d'avoir recours aux tribunaux ordinaires, et, en même temps, à la procédure traditionnelle, celle qui a fait ses preuves, qui est connue de longue date, enseignée, appliquée, commentée, « rodée » (comme on aime à dire aujourd'hui), que la jurisprudence avait mis des siècles à élaborer et à améliorer avant sa traduction dans les édits royaux, puis sa refonte en 1806 dans le Code de Procédure Civile et qui pourrait fort bien supporter des perfectionnements.

Contrairement à ce que pense l'auteur d'un récent rapport ministériel [2], ce ne sont pas les jugements qu'il y a lieu d'accuser de « confusion et d'obscurité ». L'expérience prouve qu'il est non moins injuste de « douter du soin apporté à leur rédaction ». Ce sont plutôt de nombreux textes législatifs qui méritent ces reproches. Les décisions de justice (il n'y a qu'à les lire telles qu'elles paraissent dans les recueils de jurisprudence) ne peuvent sembler obscures qu'à ceux qui, ignorant tout des questions traitées, ne savent pas quelles difficultés les magistrats ont à surmonter pour mettre en harmonie des textes plus ou moins bien rédigés, ne disant pas toujours ce qu'ils veulent dire et parfois se contredisant. La suppression des « qualités », qui répond, d'ailleurs, à d'autres préoccupations, n'améliorera pas cette situation. La cause

[1] Les nouveaux articles 168, 169 et 171 introduits dans le Code de Procédure Civile par le décret du 22 décembre 1958 devaient, dans l'esprit de leurs auteurs, remédier aux graves inconvénients résultant du trop grand nombre d'exceptions d'incompétence. Mais, ces textes, techniquement défectueux, se sont révélés mal adaptés à leur fin. Il a fallu, tant bien que mal, les remanier *six mois* après leur mise en application (décret n° 60-802 du 2 août 1960). Les plaideurs, en général, apprécieront peu les améliorations apportées par ces articles, parce que le législateur de décembre 1958 n'a pas pu ou pas voulu supprimer les causes du mal. Il maintient, en effet, les tribunaux paritaires et les juges des loyers, sans parler des juridictions spéciales à la sécurité sociale.

[2] Rapport annexé au décret du 22 décembre 1958 paru au Journal Officiel du 18 février 1959, soit près de deux mois *après* les textes qu'il concerne.

du mal est, nous l'avons déjà indiqué, l'absence de méthode avec laquelle on fabrique des lois touchant à tout.

Est-il permis d'espérer que l'avenir apportera une sérieuse amélioration à cet état de choses ? C'est douteux. Souhaitons au moins qu'il ne l'aggrave pas, car si on laissait agir l'accélération de ce mouvement de complication progressive, la tâche des juristes deviendrait impraticable. On pourrait, en effet, imaginer par une extrapolation — purement théorique, il est vrai — que dans peu de temps tous les codes, toutes les lois, seraient réformés, bouleversés en vingt-quatre heures, puis en douze, et il n'y aurait bientôt plus assez de secondes dans une minute pour fixer la chronologie des textes !

Sans en arriver jusque là, et pour s'en tenir au présent, les difficultés sont suffisamment graves pour imposer à l'esprit la nécessité d'un prompt remède. Sans doute pourrait-on se demander s'il ne serait pas possible de persuader le législateur de s'astreindre à une discipline stricte, par exemple en se soumettant au contrôle d'un organisme de coordination qui veillerait à la rédaction correcte des lois (ainsi que le fait le Conseil d'État pour les textes réglementaires qui lui sont soumis), qui éviterait les défauts que nous avons rappelés et qui aurait le pouvoir de renvoyer à nouvelle délibération toutes les fois que le texte voté comporterait la violation d'un principe fondamental, plus ou moins involontaire. Si le Parlement entendait néanmoins introduire dans notre législation une telle violation ou exception, il le ferait alors en connaissance de cause. Ses raisons seraient donc connues par les travaux préparatoires qui précèderaient la seconde discussion. Au surplus, un exposé des motifs pourrait et devrait, comme son nom l'indique, fournir à ceux qui n'ont pas le temps de se reporter aux débats les intentions du législateur.

L'adoption d'une telle réforme nous paraît très problématique. Elle dérangerait des habitudes. En outre, elle exigerait au préalable le vote d'un texte spécial, de préférence constitutionnel. Dans l'hypothèse la plus optimiste, les effets de cette réforme dans l'art de légiférer ne se feraient sentir qu'à longue échéance. Or, le temps presse. C'est pourquoi nous proposons une solution d'une autre nature, immédiate celle-là.

* * *

Le droit, nous le savons, n'est pas une science, mais une technique qui ne se ramène ni à des chiffres, ni à des formules d'algèbre. La mise en œuvre des éléments de cette technique exige un certain art [1]. Il n'est pas besoin de rappeler que les décisions judiciaires appliquant des textes généraux à des cas particuliers, le font avec les nuances, les variantes, les finesses que tout problème humain exige pour être convenablement jugé. Aussi les cybernéticiens n'ont-ils jamais envisagé, contrairement à ce qu'ont imaginé des amateurs de « science fiction », de supprimer la magistrature et de la remplacer par des machines.

Sans doute bien des personnes ont-elles lu l'ouvrage que M. le bâtonnier Jacques Charpentier fit paraître en 1954 sous le titre « Justice 65 ». C'est un conte philosophique et satirique dans la meilleure tradition des contes de Voltaire. Donc, on a aboli les juges. On a voulu éliminer le facteur personnel, les antipathies, les passions, les humeurs, les préjugés et on les a remplacés par la mécanique du Hasard, tout comme à la roulette. Les choses ne paraissent pas aller plus mal, insinue l'humour noir de l'auteur.

Mais il s'agit d'une fiction poussée en ses ultimes conséquences d'un avenir mécanisé, déshumanisé, paradoxalement justifié par la seule vertu d'une plume qui n est jamais dupe de ses jeux d'esprit.

Je sais bien que M. le bâtonnier Charpentier serait d'accord avec moi pour dire : une machine à juger, quelle monstruosité !

Les savants qui, comme M. Louis Couffignal, travaillent au développement et au perfectionnement de la cybernétique lui ont donné une définition : la cybernétique est l'art d'assurer l'*efficacité de l'action* [2]. Ils savent fort bien que leurs machines n'iront pas au-delà. Pour eux, comme pour tous les gens de bon sens, le jugement dans les divers sens du mot, reste et restera l'apanage de l'esprit humain. Encore faut-il, si on veut obtenir des jugements qui soient aussi satisfaisants que possible, qu'ils émanent d'hommes réfléchis, expérimentés, impartiaux, doués de qualités morales et ayant, de préférence, une culture juridique. Il n'est point de machine, si perfectionnée soit-elle, qui parvienne jamais à reconstituer cette coopération équilibrée des facultés humaines qui président à la formation d'une décision judiciaire.

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[1] Cf. la définition que Littré donne des arts libéraux : « ceux qui sont du ressort de l'intelligence, de l'esprit ».

[2] Louis Couffignal, *Actes du Ier Congrès International de Cybernétique de Namur*. Association Internationale de Cybernétique, Namur, 1956.

Qu'il s'agisse de résoudre le conflit de deux principes de droit ou d'appliquer un texte à des cas non prévus par le législateur (comme ce fut le cas pour l'art. 1384 du Code Civil) ou de préciser les conditions raisonnables d'application d'une règle exprimée en termes généraux, la machine ne peut fournir de réponse.

De plus, si on lui laissait développer les applications des lois selon la seule logique mathématique, sans faire intervenir les correctifs tirés du bon sens, on aboutirait à des jugements *absurdes*, donc révoltants et contraires aux normes de justice. Liberté du choix, bon sens, invention créatrice sont des qualités qui ne s'enregistrent pas sur un ruban magnétique. Ne parlons donc pas de *machines à juger*.

La cybernétique a d'autres buts. Elle peut, en effet, doter, dès à présent, la gente judiciaire de l'instrument qui lui manque et qui la débarrasserait des recherches fastidieuses et épuisantes dont nous parlions. Désormais, grâce à l'intervention de cette « dea ex cybernetica », les juristes n'auraient plus à perdre leur temps à des besognes qu'une machine saura faire beaucoup mieux et cent mille fois plus vite qu'eux.

* * *

Comment donc est faite cette machine, comment fonctionne-t-elle ? J'aimerais à la voir de près, dira l'homme curieux que cette question intéresse.

A notre connaissance, même dans les pays les mieux équipés électroniquement, il n'existe pas encore de machine servant à l'information juridique. S'il en est ainsi, ce n'est pas qu'on se heurte à des obstacles d'ordre technique. C'est parce que nul n'a encore pensé à mettre la cybernétique au service du droit. Ce que nous allons vous exposer est donc entièrement nouveau.

Comment doit-on concevoir cette machine dont l'intervention paraîtra révolutionnaire à bien des juristes ? Suffira-t-il de reprendre une machine déjà existante avec quelques modifications ? Certainement pas.

Pour qui ne le saurait pas, nous indiquerons que chaque machine électronique est conçue pour un travail déterminé et qu'elle n'en pourrait accomplir un autre, à moins de transformations considérables qui feraient d'elle une autre machine. Pas plus que le marteau et le tourne-vis, ces machines ne sont interchangeables. Elles prolongent, mutiplient et accélèrent l'efficacité des opérations

de l'esprit, mais chacune reste spécialisée et n'est utilisable que pour une finalité particulière.

Cela revient à dire que le plan des solutions techniques déjà adoptées, par exemple, pour le calcul des prix de revient ou la balistique, ne peut être transposé avec de simples changements de détails ou de signes pour s'adapter au droit. Il ne s'agit pas, comme dans une machine à écrire, d'une répartition différente de la position des lettres sur le clavier en passant d'une langue à une autre. Le problème est bien plus complexe. C'est l'enchaînement des opérations mentales auxquelles se livre le juriste sur le contenu du droit qui est en jeu. Ces opérations, en dépit d'analogies superficielles, n'ont pas leurs pareilles en d'autres matières. Il sera donc nécessaire pour obtenir le résultat désiré de combiner un ensemble formé de connexions originales de diverses machines électroniques dont le principe est bien connu et dont les applications sont courantes.

Sans entrer dans des détails techniques qui n'auraient pas leur place ici, disons qu'un premier organe recevra les questions posées et les traduira en langage codé, tel que celui du système binaire qui se compose du Zéro et du Un en diverses positions (1). Cette traduction sera automatiquement transportée sur des cartes ou bandes perforées qui passeront dans un deuxième organe, sélectif celui-là, possédant des rubans magnétiques enroulés sur des bobines à la manière des films de cinéma. Sur chacun de ces rubans on a enregistré une ou plusieurs parties de l'information juridique, droit civil, droit pénal, droit commercial, législation du travail, etc... sous la forme la plus réduite possible. Ni la longueur des rubans, ni leur nombre ne sont théoriquement limités. On peut donc ajouter au fur et à mesure des besoins toutes les notions nouvelles ou toutes les connaissances désirables. Un des rôles les plus importants des électroniciens-juristes sera de tenir constamment à jour l'information des mémoires magnétiques et d'y apporter, le cas échéant, les corrections qui se seraient révélées nécessaires à l'usage.

Le déroulement de ces films se tait à une vitesse si grande (2) que tout le droit civil, par exemple, peut être « lu » en un temps très court de l'ordre de quelques minutes, par un appareil *ne retenant*

(1) Voir annexe.

(2) Un tambour magnétique peut effectuer plusieurs milliers de révolutions par minute. L'unité de mesure en électronique est la microseconde (millionième de seconde).

que ce qui répond à la question. Un troisième organe reçoit et met en ordre les éléments de la réponse ainsi recueillie, les traduit en clair et les imprime sur le champ à une cadence accélérée (1). Le « client » recevra ensuite les feuilles imprimées qui le concernent. Selon les dispositions prises, la réponse donnera, soit les références aux textes et aux ouvrages à consulter, soit la reproduction des passages désirés.

Enfin, ces trois organes seraient dirigés par un cerveau électronique assurant la distribution des programmes de travail, ordonnant la succession ou la simultanéité des opérations de recherche, ainsi que la conservation des résultats dans des mémoires provisoires. L'ensemble formerait une machine de recherche documentaire adaptée au droit.

Grâce aux réponses qu'elle donnerait au juriste, il pourrait avoir, dans le minimum de temps d'une lecture, une vue synoptique des articles et des commentaires se rapportant à la question posée, ce qui exige présentement de longs efforts et une considérable perte de temps.

Sous quelle forme, dans quel ordre, fera-t-on ingurgiter à la machine les éléments des matières juridiques dont on voudra doter sa mémoire ? La première pensée, toute simple, qui saute à l'esprit lorsqu'on pose cette question, est de pourvoir cette machine d'autant de fiches (électroniques, s'entend) qu'il y aura de textes. Mais des inconvénients pratiques rendent cette solution inacceptable. Il n'est pas sûr qu'il n'existera pas bientôt tant de textes qu'il faudrait donner à la machine un volume si considérable que son prix de construction deviendrait prohibitif. De plus, ces fiches exigeraient, pour leur lecture, beaucoup trop de temps, d'où une lenteur relative dans le fonctionnement de la machine qui ferait perdre une bonne partie des avantages de rapidité que l'on attend de la cybernétique. Cela se ferait surtout sentir lorsque les questions imposeraient — et ce sera le cas le plus fréquent — des recherches dans plusieurs branches de législation. Comme il est exclu d'avoir recours à des interventions répétées de l'électronicien, il convient de rechercher un autre mode de répartition des matières juridiques. Il faut que l'information des mémoires magnétiques soit disposée de manière à permettre automatiquement toutes les coupes, toutes les discriminations possibles. La solution « simpliste » d'une fiche par texte doit donc être écartée.

(1) On atteint à présent, selon certains procédés, la vitesse d'impression de plusieurs centaines de lignes à la minute.

Sans doute proposera-t-on alors de classer la matière juridique par rubriques, comme le font les tables des recueils de jurisprudence ou de législation, mais de nouvelles objections surgissent. Est-il raisonnable de construire à grands frais une machine électronique pour retrouver en elle les défauts des répertoires usuels ? Outre que pour désigner une même chose ces répertoires ne se servent pas toujours des mêmes mots, ce qui est inconciliable avec la précision exigée par une machine, il faut bien reconnaître que souvent leurs tables ont leurs jeux de renvois d'une rubrique à une autre avec retour à la première, et aussi leurs lacunes, leurs fantaisies, leurs arcanes, toutes choses éminemment indésirables dans une machine dont le mérite doit être de surpasser les travaux imprimés par une perfection et par une rigueur quasi surhumaine (1). Si certains défauts mineurs sont supportables en pratique dans des recueils, parce que l'expérience nous a appris à corriger les imperfections de l'un par les qualités de l'autre, il n'en peut être de même avec une machine qui, pour bien des raisons, ne fut-ce qu'à cause de son prix, restera fort longtemps, si ce n'est toujours, unique en son genre. Il faut donc tendre *ab initio* à la doter de toutes les qualités techniquement réalisables et on doit rejeter un classement qui ne serait au mieux qu'une compilation d'ouvrages relativement imparfaits.

Abandonnant résolument les habitudes enracinées par l'usage de l'imprimé depuis plusieurs siècles, il faut repenser le problème du classement en ne tenant compte que des exigences et des ressources des machines électroniques. Comme il a déjà été construit des machines adaptées à l'information, il n'y a qu'à se servir de cette jeune expérience acquise en d'autres matières. Par analogie avec les solutions qui se sont imposées, nous dégagerons les *notions de base* dont nous nous servons sans y penser et qu'il est nécessaire de fournir à la machine. Elle est, en effet, constitutionnellement incapable du moindre raisonnement implicite ou intuitif. Or, ces notions de base seront pour elle comme des plaques tournantes à à partir desquelles elle ira chercher les éléments de la réponse demandée. Par exemple, on partira de la notion d'âge pour savoir les droits à pension alimentaire d'un enfant naturel, parce qu'il se révèle, à la réflexion, que l'âge est une dimension de l'être humain considéré comme sujet de droit. Qu'il s'agisse de sécurité sociale,

(1) Qui n'a pas souffert au cours de ses recherches de trouver quelquefois dans certaines éditions des renvois entachés de tant d'erreurs, d'omissions ou même de coquilles que la découverte, en pareil cas, de l'arrêt de Cassation ou de la référence dont on a besoin, relève plus de la rabdomancie que d'une saine méthode ?

de règlementation fiscale, de permis de conduire, du droit d'exercer certaines professions ou de se présenter à des examens, etc... il faut toujours partir de la notion d'âge. Pour représenter graphiquement le tableau des connexions juridiques selon l'âge d'un individu, il faudrait une surface considérable qui dépasserait de beaucoup les dimensions de cette table. Il suffira de quelques centimètres carrés au sein de la machine.

D'autre part, il serait nécessaire d'entreprendre une mise au point précise de la nomenclature en usage chez les juristes. Il faudra adopter des définitions claires de toutes les notions qui seront incorporées dans la mémoire magnétique. Il faudra donc expurger notre vocabulaire juridique des ambiguités qu'il recèle encore en bien des points. Ce n'est qu'après l'accomplissement de ce double travail de terminologie et de classement des notions de base que l'on pourra passer au montage et à la mise en marche de cette nouvelle auxiliaire de l'esprit humain. Dès qu'elle fonctionnera, le juriste pourrait oublier ce qu'il sait de l'électronique, pour s'imaginer avoir désormais à son service une véritable fée capable de répondre aux questions posées sur toutes les situations régies par le droit.

* * *

Quand l'habitude sera prise de se servir d'une telle machine de recherche documentaire, les progrès accomplis grâce à elle éclateront aux yeux de tous et on ne pourra bientôt pas plus se passer d'elle que du téléphone. Elle fera partie des instruments de travail auxquels le juriste aura recours comme l'architecte prévoit l'intervention de grues et de moyens mécaniques perfectionnés pour la construction des immeubles modernes. Sa rapidité, sa fidélité de mémoire, sa précision que ne rebute aucune complexité, l'ampleur des connaissances auxquelles elle peut se référer, lui donneront sur le travail des cerveaux humains des avantages si considérables qu'il n'est pas possible de les mesurer tous dès à présent dans leurs ultimes conséquences.

Loin de rapetisser le rôle de l'intelligence humaine dans l'ordre juridique, elle le débarrassera des besognes matérielles exigées par les recherches et lui fournira presque instantanément les matériaux avec lesquels l'esprit entreprendra tout ce qu'une machine ne pourra pas faire : raisonnements, déductions, jugements. Notamment, alors que tant d'États acquièrent leur indépendance et se mettent à légiférer, les possibilités de la cybernétique en droit comparé

apporteront aux spécialistes des facilités qu'ils n'auraient jamais osé rêver, il y a seulement dix ans.

* * *

Il y aurait intérêt à mesurer brièvement quelle est la place de l'invention des machines électroniques, non pas dans l'histoire de la technique, mais dans l'histoire de l'esprit. Ce ne sera, d'ailleurs, qu'une très modeste esquisse.

Nous savons qu'une grande étape et des plus décisives fut franchie par l'intervention de l'écriture, cette invention dont Cournot disait qu'elle marquait « l'époque critique de l'histoire de l'esprit humain ». Elle se place dans les ténèbres de la préhistoire, entre le 4e et le 3e millénaire avant J.C. Des savants commencent à découvrir et à classer les premières ébauches d'écriture, ces traits ou dessins auxquels l'homme attribuera une signification. Dessins bien émouvants, symboles, idéogrammes, pictographies, alphabets enfin qui forment à travers les siècles le conservatoire de la pensée humaine et d'où toute science est sortie par lente accumulation de nos connaissances.

L'écriture était manuelle et elle le resta très longtemps. Jusqu'au jour où la découverte de l'imprimerie en permit l'impression mécanique. C'était, comme chacun sait, au XVe siècle, une invention dont la Renaissance allait tirer une de ses plus grandes forces de propagation. Depuis lors, nous en étions restés là. Toutefois, la photographie nous avait au XIXe siècle permit la conservation des images ; le photographe au XXe, dans cette « Belle Époque » si injustement décriée, nous apportait la reproduction des sons de la voix et de la musique.

Mais c'est l'électronique et ses applications par la cybernétique qui, tout récemment, a fait franchir au travail intellectuel un bond au moins aussi considérable que celui de l'imprimerie. Nous voyons en l'espace de quelques années, les travaux de l'intelligence multiplier par cent mille leur vitesse, leur précision, leur mode de conservation et leur efficacité et cela grâce aux machines électroniques. Mais à ces machines, il fallait trouver un langage. Il était impossible, pour de multiples raisons, de se servir avec elles des alphabets ordinaires. C'est alors que M. L. Couffignal dans une thèse magistrale utilisa et mit au point le système binaire et en exposa les avantages et le mode d'emploi dans la technique des machines à calculer. Cette thèse est parue en 1938. Pendant la guerre, les Américains s'empressèrent de mettre en application ce système. Il a été, depuis,

employé par le monde entier. Il s'agit de l'emploi exclusif du Un et du Zéro dans des chiffres d'une longueur plus ou moins grande selon les besoins.

La cybernétique ne serait pas ce qu'elle est aujourd'hui sans l'emploi de ce système. Nous savons donc *comment est née cette invention aux conséquences infinies.* Nous savons quel en est l'auteur à qui je suis heureux d'exprimer toute mon amicale admiration. Sa modestie dut-elle en souffrir, je ne puis m'empêcher de rappeler ici ce mot de mon regretté maître Emile Mâle : « Si nous savions mieux l'histoire, nous trouverions aux origines de toutes les innovations une grande intelligence. »

ANNEXE

Pourquoi est-il nécessaire de faire fonctionner la machine électronique à l'aide d'une langue différente de celle que nous parlons et que nous écrivons ?

Parce que notre langue exige l'emploi de signes et d'une syntaxe compliquée, représentée par des lettres, et qu'il y a grand avantage à obtenir électroniquement les mêmes résultats en faisant usage d'un « alphabet » simplifié qui s'adapte aux exigences d'une machine.

Même dans des vocabulaires aussi élaborés et aussi évolués que ceux de la science et du droit, l'*idée* évoquée par un mot ou par plusieurs mots généralement réunis (ex. novation, réserve mathématique, dommages et intérêts, défaut-profit-joint) représente un un concept complexe. Nous les employons sans penser à cette complexité parce que habituellement nous n'avons pas besoin de la décomposer en éléments simples. De plus, bien des mots ayant plusieurs sens, nous ne distinguons celui qui doit être retenu que par le sens général de la phrase. Or, se référer au contexte pour choisir le bon sens est une chose que les machines ne savent pas faire d'une manière satisfaisante.

Les langues anciennes, analytiques, où les éléments du discours s'édifient par agrégation de racines ou d'affixes, ne sont allées assez loin, ni dans l'analyse pour qu'un élément simple de pensée (radical ou affixe) n'ait qu'une signification, ni dans la synthèse pour exprimer d'un mot tout un concept complexe. Les langues d'Extrême-Orient qui ont adopté des idéogrammes, c'est-à-dire un signe pour chaque concept (en principe), ont dû limiter le nombre de leurs signes parce qu'il est impossible à un cerveau humain d'en garder

en mémoire un trop grand nombre — les Chinois lettrés passaient au moins dix années de leur vie à apprendre environ vingt cinq mille signes — de telle sorte que ces langues, elles aussi, ont eu recours à des expressions elliptiques et à des périphrases.

Une machine, n'étant pas capable d'établir plus d'une correspondance entre un signe et un concept, est inapte à traduire ces nuances parfois capitales, alors que l'intelligence les perçoit sans peine par la compréhension du contexte. Pour remédier à cet inconvénient, il faut mettre à profit les possibilités presque illimitées d'enregistrement des mémoires magnétiques en classant sous un signe spécial chacun des millions de termes élémentaires dont nous nous servons.

On imagine aisément qu'un numéro peut être attribué à chacun de ces termes dans un code universellement admis. Plusieurs systèmes ont été proposés, notamment celui inventé par M. L. Couffignal, dit système binaire, dont l'adoption a ouvert à la cybernétique d'immenses possibilités de développement. Il s'agit, ainsi qu'il a été dit au cours de la conférence, de l'emploi exclusif du Un et du Zéro dans des chiffres d'une longueur variable selon les cas. Le Un laisse passer le courant, le Zéro pas. Les équations géantes avec lesquelles jouent les cerveaux électroniques reposent sur cette alternative dont la simplicité s'accorde, on le comprend aisément, avec la constitution électrique de ces machines.

Soit une machine à calculer qui accepte, dans chaque élément de mémoire, cent mille nombres de 17 chiffres sur lesquels vingt opérations différentes peuvent être faites. Si nous transposons cette faculté dans une machine destinée à l'information juridique et si nous supposons que l'on pose cette question « un mineur émancipé peut-il exploiter un débit de boissons ? », les combinaisons de chiffres adoptées par un code pourront donner, par exemple

01350030047800762

suite de chiffres qui constitue une « catène » dans la technique de la cybernétique des machines à calculer.

Le signe 01350 lancerait les recherches d'après l'âge de l'intéressé. L'âge est, en effet, un concept de base, toute situation juridique individuelle étant soumise à des règles qui dépendent de l'âge. Les deux chiffres 03 pourraient renvoyer à l'émancipation ; le n° 0478 à la règlementation des débits de boissons ; le n° 0762 aux références à la jurisprudence et à la doctrine.

En résumé, le langage de la machine n'a pas la structure des syntaxes des langues usuelles. Il repose sur une logique apparentée à celle des mathématiques et permet à une catène d'établir automa-

tiquement les relations d'un concept à une autre sans sauter par dessus les étapes intermédiaires que, très souvent, le langage parlé et, avec lui, le raisonnement habituel supposent acquises et passent sous silence. Ainsi la machine parvient-elle à la réponse demandée par ses voies propres (1).

(1) Louis Couffignal, *Information et Cybernétique : les Notions de Base*, Gauthier-Villars, 1958, et *Actes des Congrès Internationaux de Cybernétique*, 1956, et 1958, Association Internationale de Cybernétique, Namur.

A predictive model for self organizing systems

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PART II (1)

CONSTRUCTED PLAYERS

We now take our second tack and examine the system in the case when the decision rules of the players are known to be competitive. Explicitly we shall replace each player by a constructed artefact called a learning automaton — which " learns " to maximize its own payoff — and which is logically equivalent to many of the familiar " learning " by reward machines.

Such an automaton always has a set of output states and a single valued variable (in this case, for the i-th automaton, the payoff u_i which it is intended to maximize). In addition it may have a set of inputs. The output states are in one to one correspondence with moves in the game, and will be taken as binary unit impulses of interval τ. The inputs, if they exist, will be the possibly attenuated output impulses of other automata or external impulses received from the outside world. Since the automata are trying to maximize the u_i we associate them, like the players, with nodes in the network.

It is always possible to represent the workings of such an automaton in the manner of Diagram 9. Since machines of this kind have been described in some detail before, we shall merely outline the mechanism [18, 19].

The unit I is called a " resolver " and consists of n_0 elements,

(1) The first part of this article has been printed in *Cybernetica*, Vol. III, nº 4, 1960.

each of which provides a binary output-variable $\bar{\xi}_r$ for $r = 1, 2, 3, \ldots n_0$, which manifests itself as a unit impulse of length τ. The output of the resolver unit is thus a binary vector of n_0 components. Again we understand that the variables are unit impulses of length τ. The input to I is a column vector,

$$\mathcal{E}(t)\,\vec{\mathcal{L}}(t)$$

where $\vec{\mathcal{L}}(t) = \vec{\bar{\xi}}(t)$ plus input vector to automaton. The quantity $\mathcal{E}(t)$ is specified by the numerical values $\epsilon_{rs}(t)$ in the array labeled as II in Diagram 9. Initially suppose that all ϵ_{rs} are equal. In this case I acts like the trial making servomechanism described by McKay.

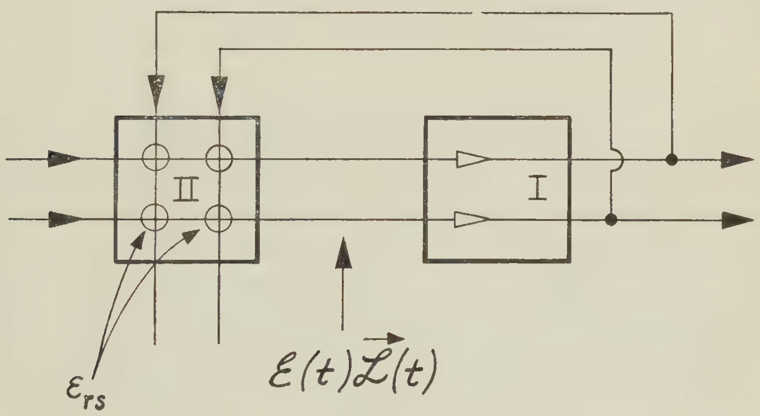

DIAGRAM 9

Each element tries to come " ON ", $\bar{\xi}_r = 1$, subject to the condition that only a subset of the available n_0 elements may be " ON " at any instant t. The condition is explicitly a monetary restriction. A certain amount of money (energy sounds more usual and is equivalent) is needed to induce the transition $\bar{\xi}_r(t) : 0 \rightarrow 1$, and the elements of i-th automaton compete for a limited u_i. The sequence of $\bar{\xi}(t)$ is determined by the rule, if

$$\bar{\xi}_r(t_0) = 1,\ \bar{\xi}_r(t_0 + \tau) = 0)$$

and

$$\mathrm{P}(\bar{\xi}_s(t_0 + \tau + \delta_t) = 1) > \mathrm{P}(\xi_r(t_0 + \tau + \delta_t) = 1)$$

for all r. Here $\mathrm{P}(x)$ is the probability of x and the index $s = 1$,

2, 3, $..n_0$. We can think of an inhibitory bias, which decays over the succeeding interval, being applied to the θ-th element at $t = t_0$ if $\bar{\xi}_r(t_0) = 1$ as a mechanism for realizing this rule. Specifically, the inhibitory bias will be a signal cost, in the sense that when $\bar{\xi}_r(t_0) = 1$, the money available to the i-th automaton's n-th element is decreased by this amount.

The input $\mathcal{E}(t)\ \vec{\mathcal{L}}(t)$ acts, on the other hand, as an excitatory bias so that, if the r-th component of this vector is high, $\bar{\xi}_r$ is more likely to equal 1. The value of this bias is adjusted so that an element does not cyclically stimulare itself. We define a quantity $\theta = 1$, if and only if $u_i > \bar{u}^*$, a critical quantity constant throughout the game. Furthermore $\theta = 0$, if $u_i \leqslant \bar{u}^*$. In this case, the change in the entries $\epsilon_{rs}(t)$ is determined by

$$\frac{\delta\epsilon_{rs}}{\tau} = \frac{\epsilon_{rs}}{\tau_0} - \frac{\theta}{\tau}\,(\bar{\xi}_i\bar{\xi}_j + \bar{\xi}_j) \tag{28}$$

The analogy of our quantity ϵ_{rs} with what previously was defined as signal distance c_{ij}, may have been observed. Hence the close relationship of this equation (28) with equation (3), which described the temporal changes of the signal distance due to the activity of the players. Again, the first term in equation (28) describes an exponential depreciation of ϵ_{rs} with time.

While the offer-directing rule implied by the term

$$\frac{1}{\tau}\,\bar{\xi}_{ij}\,c_e$$

in equation (3) is now replaced by the coincidence rule implied by the term

$$\frac{1}{\tau}\,\bar{\xi}_i\,\bar{\xi}_j\,\theta$$

The last term in equation (28)

$$\frac{1}{\tau}\,\bar{\xi}_j\,\theta$$

has the corresponding property to the last term in equation (3) namely, to preserve the establishment of an entry ϵ_{ij}, once constructed.

Concentrating upon the term $\bar{\xi}_i\,\bar{\xi}_j\,\theta/\tau$, it is clear that the entries

in II increase only if a combination of events is associated with a high value of u_i. Since these entries determine the behavior of the automaton, acting, as they do to connect the elements into a coherent whole, the automaton will build up only those connectivities which lead to high values of u_i. Thus, since it seeks to maximize u_i the i-th automaton will clearly compete in M with a further j-th automaton seeking to maximize u_j whenever it is the case that the payoff function is competitive, i.e., when increase in u_i implies a decrease in u_j.

We can readily demonstrate this propensity by choosing an M which determines a competitive payoff function and allowing two automata to compete. Their behavior will approach the usual iterative solution procedure for a two person competitive game[20].

Boundaries of the automata

If, as in Diagram 10 we embed the automata in a signal space wherein the signal distance from the i-th automaton to the j-th automaton is determined by a relation

$$\frac{\delta c_{ij}}{\tau} = \frac{c_{ij}}{\tau_0} - \frac{c_e}{\tau} (\bar{\xi}_i \bar{\xi}_j + \bar{\xi}_j) \qquad (29)$$

there is no real distinction between the " inside " and the " outside " of an automaton for (28) and (29) are identical except in the names given to the variables and possibly the values of the cost parameters. We assume that these parameters are identical and point out that " A " and " B " in Diagram 10 will, in this case, be isomorphic. The elements must pay for the construction and maintenance of " internal " connections (the existence of which makes the set of elements act as coherent automata in the same way that an automaton must pay for the construction and maintenance of the external connections (which allow it to act as part of a coalition). There is no objection to using the idea of bounded automata as a descriptive expedient. Indeed we do this when we talk about an observer partitioning of the set of elements. But it is important to realize that these boundaries exist only for the observer's convenience.

The hinterland of the self organizing systems

In particular, we define a self organizing system in terms of the

type of partitioning an observer is able to use, saying that a system is self organizing if the observer must, in order to make sense of it, choose a fresh partitioning into competitive entities at each instant. We shall examine the transition from systems in which this is not a necessary expedient, into those self organizing systems in which it is.

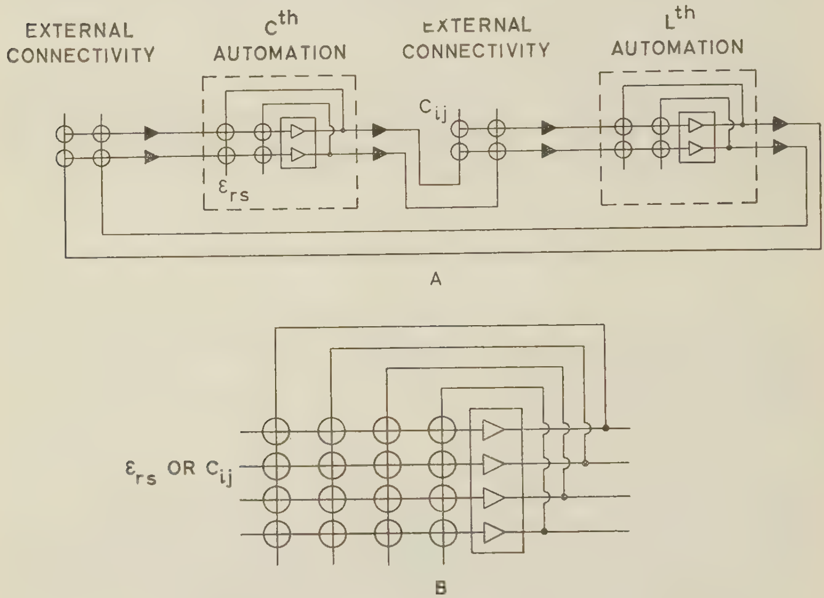

DIAGRAM 10. — Diagram A reduces, by relabeling elements, and noting that the competitive action of the resolver is equivalent to a particular monetary neighborhood specification to Diagram B, where, if two elements are in the same □, this implies that the nodes associated with the ▷ elements are monetary neighbors.

Suppose we have a network M with n nodes associated with active elements and rules for the decrease of signal distance such as (28) and (29). In the simplest case the signal distance may remain invariant. In this case we can partition the active elements, once for all, into subsets which compete with one another. On the other hand the signal distances c_{ij} (the connectivities of the elements) may change so that we cannot say one region is always richly connected relative to its surroundings (and should on this account be deemed a competitive automaton). Even so, if n is invariant, and if it is possible to index the nodes, we can construct $C(t)$ and, by time averaging, discern regions in which the connections are rich when viewed statistically, over an appreciable time interval.

These regions are then taken as statistically bounded competitive automata embedded in the network. Indeed if we *can* index the nodes, either

(i) such statistical assertions are possible, or
(ii) the activity in the system is incomprehensible,

and when (i) rather than (ii) applies, an observer can adopt a statistical partitioning. But we *need* not be able to index the nodes. The point is, that the picture we have just examined is appropriate either for determinate (fixed signal connectivity) systems or for systems in which connectivity is paid for (as a channel construction and maintenance cost) but where the *elements* exist independently. It is no longer appropriate if the elements themselves must be *paid for* in the sense that they survive if, and only if they are successful.

We shall construct an abstract system of this kind in a moment. We note immediately that it will often appear to be a system with invariant elements, for example, the number $n(t)$ of elements may not change and it may, because of this, be possible to construct an empirical " connectivity " $C(t)$. The important point is that the elements which exist at $t = t_0$ and $t = t_0 + \tau$ will, in general, be different. They cannot be indexed as the same. $C(t)$ refers not to the signal distance between real elements, but to connectivity between constructs of the observer's own making. These constructs have the same status as cells, or bits of a cell, in a biological system. They, like the cell, are an organization which is invariant (an organization which amounts to, in this case, the least thing which competes) and the observer has chosen *this* as the unitary component in his description.

So, when he comes across a system where the elements are paid for, the observer is bound to change his partitioning (and thus, by definition, to call the system self organizing) if he wishes to demark regions which *are* competitive. Other kinds of systems may be self organizing — this kind must be.

Construction of abstract system

It can always be argued that an " abstract " self organizing system is absurd, for all it can mean is a set of loosely phrased instructions given to the maker of an artefact. A particular artefact (we present a pair of realizations in appendix II) has particular equations. In the " abstract " system we specify only the form

of the equations. This is all we can do since the real life constraints are determined by the material from which the artefact is built, i.e., protein, tin and alcohol, malleable artificial neurones in Murray Babcock's [33] simulator. However, for what it is worth, we shall describe an abstraction and, for this purpose we pose, as in Diagram 11, an indefinitely large number of nodes with monetary

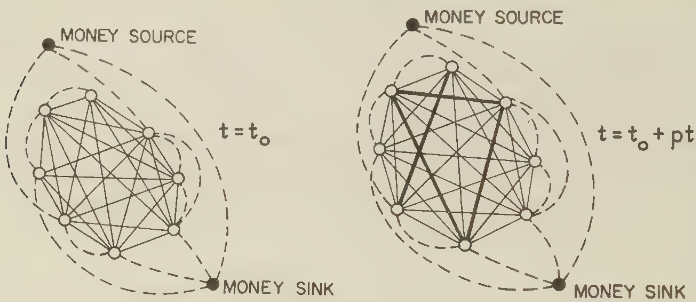

DIAGRAM 11. — Although a large number of nodes is assumed, a system having only N = 8 nodes is sketched. Thickness of unbroken lines indicates signal distance. Dotted lines indicate monetary distance.

distances m_{ij} and initial conditions such that all nodes are signal equi-distant and all $c_{ij}(t_0) = c_{ji}(t_0) =$ a very large number In M certain nodes are distinguished as *sources* and others as *sinks* via which monetary inflow and outflow occurs and we shall conceive the activity of our abstract system as directed towards " capturing " as much money as possible. The rule is applied to each element separately, i.e., each element tries to " capture " as much as it can, so that elements compete with each other, and the system competes for as much as it can get as a whole.

We define, for each node, a nucleation variable Π [21]

(i) $\Pi_i = 1$, if and only if there is an element at the i-th node,
(ii) $\Pi_i = 0$, if not.
(iii) $\Pi_i = 0$, initially.
(iv) $(\Pi_i = 0) \rightarrow (\Pi_i = 1) \ldots \Delta\Pi_i = +1$, is called a $(+\Pi)$ – transition, or " nucleation ", and occurs at time t if and only if $u_i(t) = u_{\max}$, and $\delta u_i / \tau > 0$.
(v) $(\Pi_i = 1) \rightarrow (\Pi_i = 0) \ldots \Delta\Pi_i = -1$, is called a $(-\Pi)$ – transition, or " denucleation ", and occurs at time t if and only if $u_i(t) = u_{\min}$ and $\delta u_i / \tau < 0$.
(vi) $(\Pi_i = 0) \rightarrow (\Pi_i = 0)$ or $(\Pi_i = 1) \rightarrow (\Pi_i = 1) \ldots \Delta\Pi_i = 0$, in the range $u_{\max} > u_i > u_{\min}$.

The $(+\Pi)$ – transition absorbs wealth at a rate ω_1 during the nucleation process lasting the time interval τ. This can be taken as used up in creating the structure of an " element ", in much the same way that money is used in building connective structures. The term " nucleation " is borrowed from physical chemistry, because in some systems energy is required to create crystalline nuclei. To clarify the idea we refer to Diagram 12.

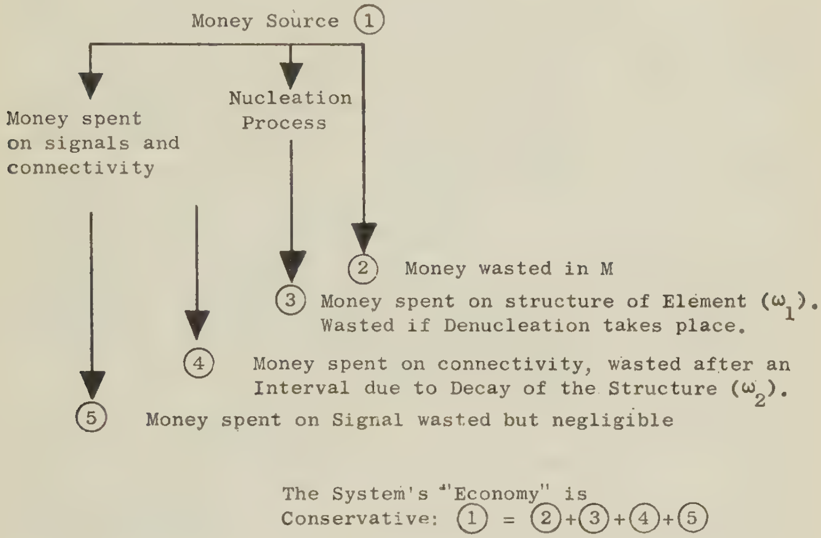

DIAGRAM 12

In keeping with the previous usage we suppose that elements, once they are formed, have a transfer function comparable to an " artificial neurone " such as

$$\xi_i = 1 \text{ at } t = t_0$$

if and only if

$$u_i \sum_j \varphi(c_{ji}^{-1}\xi_j) > \theta$$

where θ is a positive threshold, and the function $\varphi(c_{ji}^{-1}\xi_j)$ will, in general, be a temporal stretching of the unit impulse ξ_j, attenuated by the coefficient c_{ji}^{-1}. The temporal stretching may, for example, be of exponential form. In addition to the " nucleation cost " ω_1, as introduced just before, we shall now introduce a signal cost ω_2 in analogy to our concept of the cost of offermaking w, which was described earlier in equation (6) and (8). Interpreting the " cost

of a signal " as the price to be paid for a unit connectivity, we may write the changes of wealth δu_i during an interval $\delta t = \tau$ in analogy to equation (8) in the following form

$$\frac{\delta u_i}{\tau} = -\sum_i^N \frac{\Delta u_{ij}}{m_{ij}} - \omega_1 (1/2)[\Delta\Pi_i + (\Delta\Pi_i)^2] \qquad (30)$$
$$-\omega_2 \bar{\xi}_i (1/2)[2\Pi_i + \Delta\Pi_i - (\Delta\Pi_i)^2]$$

The three terms on the right hand side of equation (30) have the following influence on the rate of change of u_i in time unterval τ:

(i) Gives the gains and losses in u_i of the element i due to either negative or positive differences Δu_{ij} of element i with respect to all other elements, sinks or sources $j = 1, 2, \ldots n, n+1, n+2, \ldots N$. Since connections with sources are included in this count, this term takes care of the " wealth (or energy)-input " into the system.

(ii) Describes the " nucleation costs " because the expression in brackets [ ] will assume the value (+ 2) only if nucleation occurs. At all other instances, particularly during denucleation ($\Delta\Pi_i = -1$), this term will vanish.

(iii) Indicates the " signal cost " occurring during an active state ($\bar{\xi}_i = 1$) of element i. The expression in the bracket will assume the value (+ 2) only if this point is in a state where it can be active ($\Pi_i = 1$) and ($\Delta\Pi_i = 0$). At all other instances it will vanish.

Finally we introduce a survival rule, such that the more active the i-th element is, the more stable will it be against fluctuations in u_i. Since this stability is determined by the difference $u_{\max} - u_{\min}$ an appropriate survival rule will be

$$u_{\max} - u_{\min} = u_c[1 + 1/p \sum_{k=0}^{k=p\_} \xi_i(t_0 + k\tau)]$$

whereby u_c is an appropriate positive constant.

Origin of the activity

Initially U* must be low valued, since we have assumed that initially all $\Pi_i = 0$. But, if the inflow of money from the sources exceeds the outflow of money through the sinks, the value of U* will increase. Eventually, nucleations will occur in some regions, and from (30) this will tend to decrease U*. All the same, if the

monetary inflow is sufficient U* will continue to increase, and, from (28), coincident activity will give rise to a decrease in the signal distance between the active regions. This will effect the subsequent activity of the elements in a way which depends upon M,Ψ, as determined by the initial signal distances, the inertial parameters, and the particular equations of the artefact under consideration.

However, for all artefacts, a specified U* will give rise, on the average, to an equilibrium number $n(t) = \sum_i \Pi_i(t)$ of active elements at a certain time t. Increase in U* (amongst other things) will increase this number and decrease in U* will decrease it.

Relation to other systems

Equation (30) resembles (8) apart from the absence of an explicit profit and lack of any explicit " offer making " procedure which causes a profit. In fact, the difference between (30) and (8) is largely artificial. The i-th element makes a profit whenever $\delta u_i > 0$ and it is conceivable that the signalling activity (in common with offer making) induces a state of affairs in which indeed $\delta u_i > 0$ when this would not, otherwise, have been the case. All we have done is to replace a special profit condition by one which is more general (so that profit depends upon our choice of M, the available sources and sinks, and the coincidence of events in the system). We remark that w was introduced into the social experiment *because* we wished to assume that trade could occur and sustain itself *even if* there were no sources or sinks, and for other, quite obvious, reasons dictated by experimental convenience.

Thus we do not need to replace the particular restrictions of the social experiment in order to say that it and the present system are one of a kind. On the other hand, we can introduce other conditions, either for experimental convenience as before, or in order to utilize a self organizing system. To illustrate the points a pair of conditions will be specified.

(i) The elements act upon their *monetary* distance as well as their *signal* distance from one other. This happens to be a very common biological condition, if, for example, we interpret an " element " as a small and motile " animal ", able to move in a dish of nutrient medium (the network M) in which there are gradients of foodstuff concentration (the distribution of u_i). Changes of m_{ij} imply movement of the i-th animal with respect to the j-th animal in a food

concentration space which can, if we know the concentration gradients, be transformed into movements of the animals in the dish of medium.

Let Φ_α and Φ_β represent two presently unspecified functions; then an appropriate abstraction of the situation as described above would be

$$m_{ij} = \Phi_\alpha[\frac{1}{pu_c}\sum_{k=0}^{k=p_-}\xi_i(t_0 + k\tau)u_{ij}(t_0 + k\tau)] \qquad (31)$$

where u_c is a constant.

(ii) A second, very general condition derived by applying a transformation T* somewhat analogous to the transformation T of (21). By analogy with (21) let $\mathcal{J}_0^*$ be an $n(t)_0$ dimensional array with entries equal to 1 for those outcomes which equal 1 when the strategy σ_0 in G_0, σ_0, B_0 is used.

$$T_0^*(G_0^*) = G_0^* + \mathcal{R}\mathcal{J}_0^* \qquad (32)$$

The transformation T* is effected by specifying a special source l and adapting (31) to read

$$m_{il} = \Phi_\beta[\frac{1}{pu_c}\sum_{k=0}^{k=r_-}\xi_i(t_0 + k\tau)u_{ij}(t_0 + k\tau)] \qquad (33)$$

The particular function and the choice of wealth at the node l determine the value of $\mathcal{R}$. We suppose that $\mathcal{R}$ is controlled by either an observer who examines the activity in the system and, if he approves of it, increases $\mathcal{R}$, or by a computor which evaluates some function of this activity and increases $\mathcal{R}$ if a logical criterion is satisfied.

The most general specification of a self organizing system

It is possible to characterize a self organizing system (in the sense of giving instructions to an artefact maker) at a very general level indeed. To do so we note that C(t) can be realized by any system, or material, the states of which satisfy the topological postulates for type I habituation set out by Ashby [22]. Moreover, assignment of different inertial parameters in Ashby's system clearly gives rise to different Ψ functions. We thus combine a system called the "environment" m which embodies M, and a

system which embodies the topology already mentioned, through an interface. The interface is such that nucleation can occur, and where it has occurred, competitive " elements " will exist [23]. We can then say that for a given Ψ and an M which determines the payoff functions of essential non-zero sum games (for the given Ψ and the decision rules or transfer functions of the elements) there is a U* such that a self organizing system will arise at the interface.

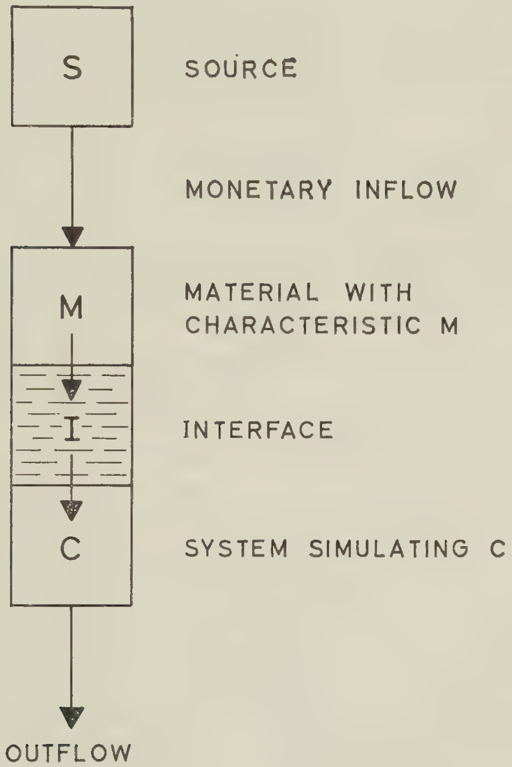

DIAGRAM 13

The important point is that the required combination of characteristics can be realized as an artefact — indeed — in a vast number of different artefacts. Our assertion determines, precisely, those environments in which a specified self organizing system can be expected to survive (Diagram 13).

Further development of structural and dynamic ideas

We are now in a position to examine the issues which remained open after our previous discussion, for now we can infer, rather than hope for, rational behavior.

(1) We previously argued that if the payoff function determined by M specifies an essential game, a coalition structure B_e will tend to form. Thus a physical connectivity (able to mediate B_e) will tend to develop, depending upon the extent to which r_e is less than the gain due to having B_e. Further, B_e will be mediated by that A_{eh} which is

(i) least costly to maintain and
(ii) adequate with respect to the competing automata. We shall assume (i) and concentrate upon (ii).

Suppose there exist certain automata — demarked either in a determinate or statistical sense — the adequacy of a given A_{eh} for mediating B_e depends upon their memory capacity. Recalling, e.g., the case of $n = 3$ [1], and supposing $B_e = B_5$. Any of $A^{\#}_{5,1}$ to $A^{\#}_{5,12}$ are adequate for an automaton having a three stage memory ; any of $A^{\#}_{5,9}$ to $A^{\#}_{5,12}$ for an automaton with a two stage memory ; and only $A^{\#}_{5,12}$ for an automaton with a one stage memory. In general, it is possible to trade memory " inside " an automaton for richness of connection " outside " an automaton. However, if (28) and (29) have the same cost parameters, as we have supposed, then the cost of acquiring " memory " inside, and connections outside is identical. In some cases it may, in others it may not, be worth making the internal and external distinction. If there were different cost parameters in different regions, it would be worth while. If we have a region in the system which does, in fact, persist, it may also be worth while. But, in the general case, with no special constraints, it is sufficient to specify the status quo at $t = t_0$ and the Ψ function which depends upon the cost and inertial parameters.

(2) Since a coalition has " memory " as a consequence of the connections whereby it is mediated, we predict that $A^{\#}_{eh}$ other than

[1] See *Cybernetica*, Vol. III, nº 4, 1960, p. 288.

the least expensive adequate $A^{\#}_{eh}$ will appear in a system which has been in existence for an appreciable time.

The stability of B_e with respect to arbitrary variations in U* clearly depends upon the number of redundant cycles in $A^{\#}_{eh}$ for any decrease in U* below a critical limit can obliterate one or more of these. Further, the process is cumulative, for suppose that a cycle is obliterated, and that B_e can no longer exist, the money available to the members of $F \subset B_e$ will decrease on this account. Since a system, or parts of it, are subject to many variations in U* over a long time interval we argue that the system, or parts of it, will learn to realize coalition structures in a redundant manner. There is a deal of evidence to support this view [24].

(3) For a given U* and a given B_e, the most stable connectivity to mediate B_e is rarely a single $A^{\#}_{eh}$. Since there are usually a number of $A^{\#}_{eh}$ with the same maintenance cost $\mathcal{R}_{eh}$ we pose the existence of a mixed or hybrid form of $A^{\#}_{eh}$. If it existed, such a hybrid form as

would clearly have an enhanced stability against arbitrarily distributed disruptions. If we assume that the competing automata are well defined, such a hybrid form is untenable — for each component would require construction — at a cost of r on each occasion (in other words, r acts as a monetary hump). On the other hand, we have argued that the competing automata are not well defined, in which case a hybrid is possible (there is an obvious and probably valid analogy with chemical systems. If we regarded a molecule as a well specified entity reactions would not occur. The structural hybrid corresponds, of course, to a resonant system). Apart from hybrids amongst the $A^{\#}_{eh}$ we can argue, in a similar way, in favor of hybrid coalition structures. In particular stationary states represented by a mixture of the games

$$G_1^*,\ \sigma_1,\ B_1 \rightleftharpoons G_2^*,\ \sigma_2,\ B_2$$

is often more stable than G_1^*, σ_1, B_1, or G_2^*, σ_2, B_2 alone.

(4) Several kinds of game can be played in the system, depending upon the over-all conditions. We shall examine what occurs if U* is varied for M and Ψ specified. For the present purpose five cate-

gories of game will be examined, but a more detailed analysis is possible. To be specific, suppose the signal space is fully connected so that initially for all i, j

$$c_{ij} = c_{ji}$$

and that the inertial parameters are chosen so that decay of connectivity is slow compared to its construction.

As U* is increased, nucleation occurs at some isolated point. The process of nucleation is described by a survival game; its logic is the same as the gamblers ruin problem [8]. As U* is further increased, there will be several nucleated regions which necessarily remain signal isolated because there is not enough money to build up signal connectivity between them. Their interaction is thus described by an inessential game. This will be so, incidently, regardless of M.

At this point, if M determines inessential payoff functions, the system behavior is always represented by an inessential game until U reaches a point at which competition is no longer possible, everything is surfeited, and the system probably melts. On the other hand, if M determines essential game payoff functions, coalition structures arise and the game is partly cooperative. In general, these coalition structures will be Ψ stable. As U* is further increased we come into the region of Ψ metastable play (1). Two necessary conditions for realizing this region (over and above those already mentioned) are (1) that the game is non-zero sum and (2) that the number of nodes in M is a function of the activity. If the game had been constant sum (or zero sum) increase of U*, it would have terminated under Ψ-stability. If conditions (1) and (2) are satisfied, the system only melts after it has passed through Ψ-metastability, which we identify for obvious reasons with the activity of a self organizing system.

These games are ordered by inclusion. All survival games are special cases of competitive games, all competitive games of Ψ-stable partly cooperative games, and all Ψ-stable partly cooperative games of Ψ-metastable games. The argument is illustrated in Diagram 14.

Suppose the special but interesting case of variable n where the system is a self organizing system. When we decrease U*, we are left with a surplus of players and connectivity. Clearly

(1) The term is introduced in this paper and does not appear in the literature. However, there are many references to a combination of sequential theory and Ψ stability theory amounting to the same thing.

the decay of the system may be more or less haphazard resulting in any of the empirically distinct paths of Diagram 14. The dynamics of this decay can, incidently, be expressed as an "attrition game", but we shall not pursue this point. We propose that an appropriate measure of the stability of a self organizing system can be obtained by first increasing and then decreasing U, by using the transformations T already discussed, repeating the cycle upon

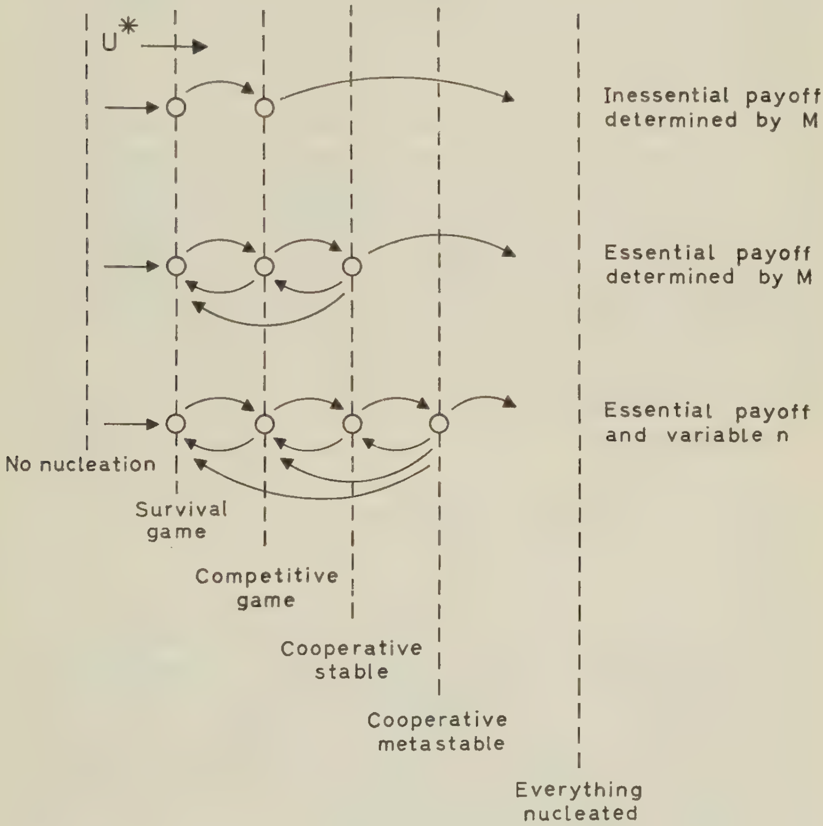

DIAGRAM 14

several occasions, and couting the number H_z of occasions upon which the system decays by the path. The proposed stability measure is then if $z = 1, 2, 3$

$$\frac{H_1}{\Sigma_z H_z} \tag{34}$$

and its adequacy will increase as the number of categories of game, and thus the number of alternative paths, is increased.

The self organizing system regarded as a learning machine

It is possible, and often convenient, to regard the automata and their interconnections as a system which is learning about the distributions of money in M. Study of the game then becomes a study of the dynamics of a learning system which are, otherwise, quite intractable.

In the simplest case, we take M to define an environment. Usually we allow the system to act upon its environment as well as react to it by specifying rules such as given in equation (31). In a slightly more elaborate case we regard M as the usual environment of the system and require the system to learn about perturbations (which we impose upon the usual environment) called stimuli. We might, for example, ask the system to produce (after a training interval) a given change of state in response to a stimulus, or a category of stimuli, or to make the same response for all of a group of transformations of a stimulus pattern.

Two different kinds of processes can be loosely distinguished within the system :

(i) an evolutionary process, whereby connective structures, reminiscent of networks, are built up, and

(ii) the action of these networks, once they exist, in transforming signals and stimuli.

True, the triple G_0^*, σ_0, B_0 specifies both the network and its activity, at an instant $t = t_0$. Strictly these are inseparable, but, so far as we can effect a distinction, our comments refer to (i). McCulloch and Pitts [25] have already dealt with the issues of (ii). We are concerned with how their " networks " — or the " logical filters " characterized by Lettvin [26] — arise in the stationary states of a self organizing system.

Identification of features of the model with those of a learning system

We assume that the system is in a stationary state at $t = t_0$ and its activity is represented by the triple G_α^*, σ_α, B_α (the letters α, β, ... will be used to distinguish particular entities rather than

the moment at which they appear). At $t = t_0$ we shall perturb the system. It is convenient to think of a perturbation Γ as a sudden change of $\vec{u}$ but a more general connotation is permissible. Any perturbation will induce a transformation $Z(\Gamma, (G^*, \sigma, B))$ of G^*. In the following we shall write simply $Z_1\, Z_2 \ldots$ for different induced transformations in place of the full specification $Z_1(\Gamma, (G^*, \sigma, B))$ in the interest of brevity.

Let $\mathcal{T}$ be the set of transformations $T^*(G)$ which, we recall from (20) and (32), can be generated if $\mathcal{R}$ is given each of its possible values. In a real system the variable will be quantized by uncertainty, so that $\mathcal{T}$ is a finite set.

Using the words as they are commonly used in connection with learning and perception, we define :

(1) *Stimulus* : any perturbation such that the transformation Z, which it induces, it not included by the set $\mathcal{T}$.

(2) *Reward* : any perturbation such that the induced transformation is included in the set $\mathcal{T}$. In this case we call the generating variable $\mathcal{R}$ a " reward variable ".

We shall also have occasion to identify aspects of our model with

(3) a response, and

(4) the process of learning.

Stimuli

It is useful to distinguish several kinds of stimulus according to the length of perturbation (whether it is a step function or a unit impulse) and according to the ensuing behavior of the system (whether it is indifferent to the stimulation, whether it adapts, and so on). As a first approximation we shall describe *five cases* of stimuli, applied at $t = t_0$.

Case 1. The stimulus is a step function but the system is indifferent to it, i.e., the stimulus induces a transformation Z_1 of G^*_a but the pair σ_a, B_a, remains unchanged. Since a stationary state G^*_a, σ_a, B_a, exists at $t = t_0$ we know from (23) and (24) that $G \Rightarrow \sigma_a, B_a$, and that $\sigma_a, B_a, \Rightarrow G\alpha$. If the pair σ_a, B_a, remains invariant $Z_1(G^*_a) \Rightarrow \sigma_a, B_a$, and $\sigma_a, B_a \Rightarrow Z_1(G^*_a)$. Thus we represent the change as in Diagram 15.

For specified Ψ the set of indifferent stimuli is, in principle calculable for each stationarv state G^*_a, σ_a, B_a and it may be

helpful to think of the set in this way. Suppose you are playing some game. At $t = t_0$ the payoff function is changed. The indifferent set is the set of all those changes which could be made at $t = t_0$ and which would not, even after the players had found out about them, cause you or the other players to modify your alignment in coalitions or to change the strategies you used.

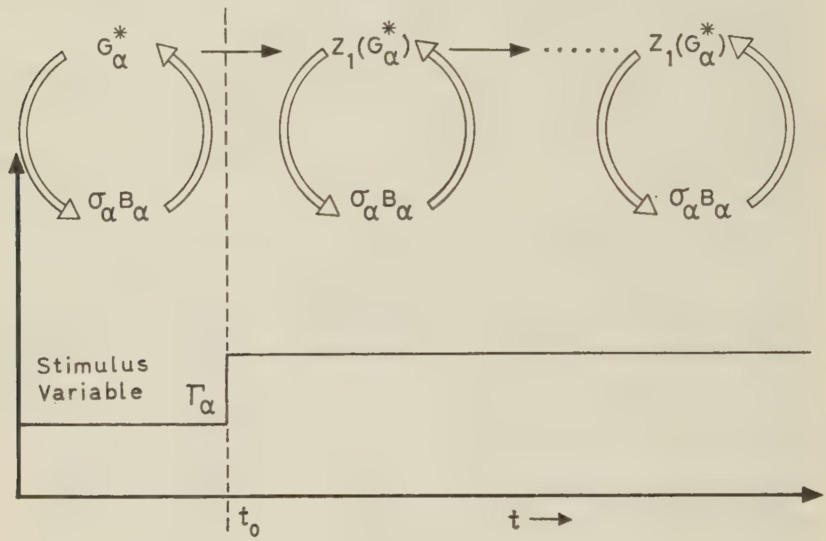

Diagram 15

Case 2. The stimulus induces a transformation Z_2 of an existing stationary state G^*_α, σ_α, B_α ; but the transformed system $Z_2(G^*_\alpha)$, σ_α, B_α is not in a stationary state. We first describe the case in which adaptation of the pair σ_α, B_α, $\rightarrow \sigma_\beta$, B_β, takes place in a finite interval $p\tau$.

At $t_0 + p\tau$ we shall discover a stationary state G^*_β, σ_β, B_β. But in general $G^*_\beta \neq Z_2(G^*_\beta)$. Rather than arising immediately, G^*_β has been reached by a process which we approximately depict in Diagram 16.

If these remarks pertain, we call the stimulus intelligible to the system in an initial state of G^*_α, σ_α, B_α. We notice, however, that although the stimulus gives rise to a stable pattern of behavior G^*_β, σ_β, B_β, this is not necessarily the pattern which an outside observer would " like " nor is it necessary that the same pattern is achieved from each initial stationary state.

Case 3. The stimulus induces a transformation Z_3 such that the

process depicted above does not converge to a stationary state within an arbitrary finite interval. In this case we say that the stimulus is unintelligible within this interval, leaving it open as to whether or not the stimulus becomes intelligible later.

Case 4. We are chiefly interested in intelligible stimuli as described in Case 2. We now ask to what extent can the transformation G^*_α, σ_α, $B_\alpha \rightarrow G^*_\beta$, σ_β, B_β be reversed. It is unlikely, for example, that mere removal of the stimulus will induce the reverse procedure. In general, as shown by Ashby, systems of this kind will adapt or habituate. We say that the stimulus is reversible within the repertoire of the observer if, within a finite set or repertoire of perturbations available to the observer and including the element "no perturbation", there is an ordered subset *a*, *b*, ... such that the cycle indicated in Diagram 17 can be induced.

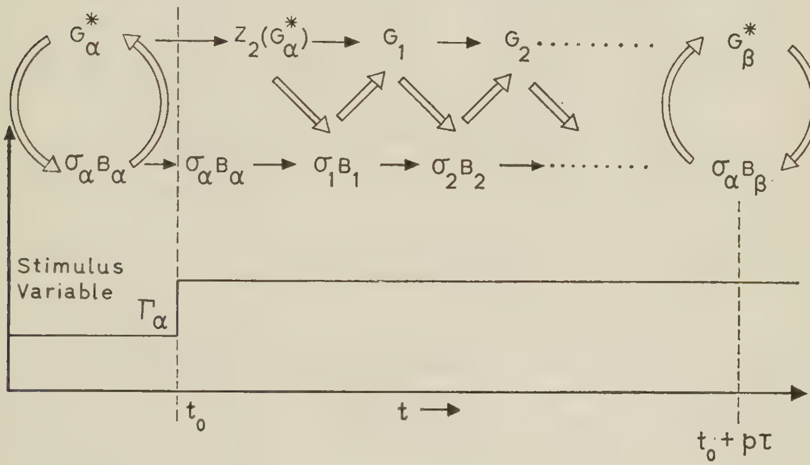

DIAGRAM 16

Case 5. A partial exception to the argument of Case 4 that a perturbation will be unlikely to reverse the transformation G^*_α, σ_α, $B_\alpha \rightarrow G^*_\beta$, σ_β, B_β is provided by Case 5 where the stimulus is a unit impulse. For reasonable choice of Ψ the transformation $Z_5(G^*_\alpha)$ induced by the perturbation will not persist long enough to change the connectivities in the system. Only the strategies will be changed and, in general, the change will not give rise to even a momentary stationary state. Using the previous convention, Diagram 18 illustrates the changes associated with a unit impulse

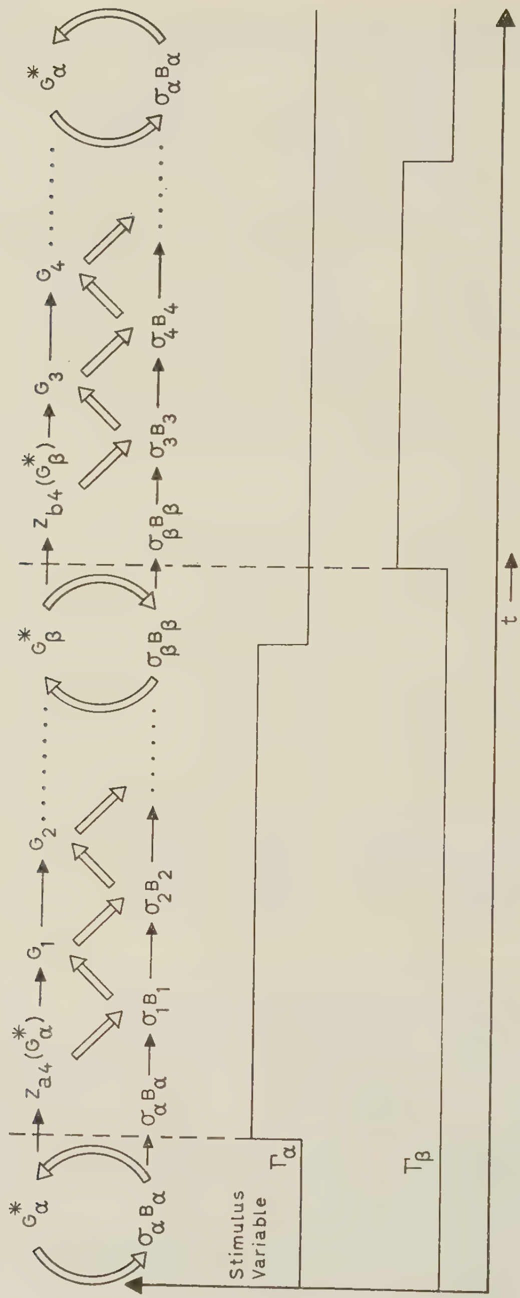

Diagram 17

of stimulus. Note that most stimuli of interest will be intelligible to the system, and will lie in the hinterland which separates Case 4 and Case 5.

Reward

There is a basic theorem [8] which asserts that the strategic character of a game is unchanged by an additive or by a scale converting transformation of the payoff function. The transformation T* is of this kind.

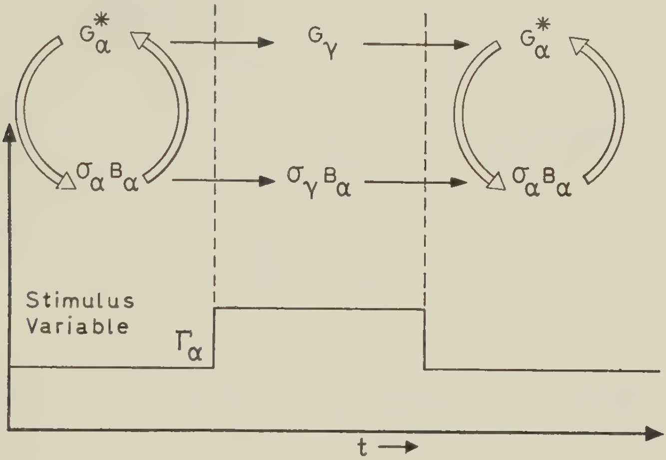

DIAGRAM 18

Thus if the game played in the stationary state G_α^*, σ_α, B_α exists, we have $G_\alpha^* \Rightarrow \sigma_\alpha$, B_α, and from the argument above $T^*(G_\alpha^*) \Rightarrow B$ also. G_α^*, σ_α, B_α and $T^*(G_\alpha^*)$, σ_α, B_α are strategically equivalent.

In the sense that G_α^* induces the construction of structures that serve a given purpose, $T^*(G_\alpha^*)$ increases their rate of construction if $\mathcal{R} > 0$. We can construe this as a rule for replicating things which serve a given function (in particular, coalition functions) for, if σ_α, B_α, sustained G_α^* up to t_0, the transformation $T^*(G_\alpha^*)$ at t_0 is an instruction to replicate the organization which has evolved in the past [24], provided $\mathcal{R} > 0$.

Two mechanisms are at work. The first is that the transformation T* with positive $\mathcal{R}$ increases the available money U* and this in turn makes it possible to realize a greater diversity of $A_{eh}^{\#} = b_{eh}$ able to realize a given B_e.

But the comment applies to any connectivity whatever. The second mechanism dictates that only those which mediate B_α will be developed if the system is in the stationary state G_α^*, σ_α, B_α. Whilst the immediate consequence of reward is permission to build more of a kind, the lasting benefit it confers is stability. We have already argued that the existence of many organizations, in particular, of many possible $A_{ah}^\#$ to mediate a single B_α begets a system which is stable against monetary deprivation and chance disturbances. Thus we have, in a rewarding procedure, that which builds up redundancy of method for doing a job which can itself be made arbitrarily specific. We identify this redundancy with McCulloch's Redundancy of Mechanism, of parallel computation [17].

Strictly these arguments apply only when n is invariant. In the most interesting case, the number of elements will increase

$$n(t_0 \times \tau) > n(t_0)$$

if

$$G_0^* \rightarrow T^*(G_0^*)$$

and

$$\mathcal{R} > 0$$

But if the increase of n occurs symmetrically (that is, if it occurs on average in a similar way for any subset of elements we choose at the instant t_0) our arguments still apply, for in this case we can regard the players (the smallest considered subsets of elements) as invariant entities with an internal structure which becomes more elaborate. We conjecture that the variation in n will rarely vitiate the argument, but will not pursue the issue further in this discussion.

Responses

A response construction is a many to one mapping of states of the system into a set of variables $Y(t) = y_1(t), y_2(t) \ldots$ called response variables and assumed for convenience to be binary. Given this assumption we regard $y_k(t_0) = 1$ as an event or "response" k, at $t = t_0$ and say if $y_k(t_0) = 0$ that the k-th "response" did not occur at $t = t_0$. A very large number of response constructions are possible and, in this paper, we shall describe only two representatives.

(1) For the first response construction we select a subset of n' nodes and define $y_i(t)$ as a function of the $u_i(t)$ for $i = 1, 2, \ldots n'$.

$$y_i(t) = 1 \text{ if and only if } u_i(t) > u_j(t)$$

for

$$j = 1, 2, \ldots n'$$
$$y_i(t) = 0 \text{ if not.}$$

By analogy with a Turing machine, M is being used as the " tape ". The stimulus perturbation is an input derived from the " tape ", and the response is an output which the system writes into it.

(2) For the second response construction it is more convenient to think about the system as an oscillatory network of the kind described by R. L. Beurle [1], in which the strategies appear as waves of activity, and in which U* is equivalent to a level of excitation. We can now suppose that there is a spatial distribution of U* about the nodes of M such that U* is high in some central region but falls off rapidly in value outside the boundaries of this region. Assume, for example, that the distribution is circular (in a plane) or spherical (in a three space) with an arbitrary origin at O and with radius ρ so that

$$U^*(\rho) > U_0^* \quad \text{for} \quad \rho < \rho_1$$

and

$$U^*(\rho) = U_0^* / (\rho - \rho_1) \qquad \text{for } \rho \geqslant \rho_1$$

In our model U_0^* is equivalent to the critical excitation level in R. L. Beurle's paper and we may thus conclude that there will exist (given these conditions upon the distribution of U*) a circle (or a sphere) of statistically constant radius, and with its center at O, at which a wave of excitation in the central region has been attenuated to the excitation of a single element. We thus number the elements upon such a line, or surface, with the indices k of the *response variables* and say that

$$y_k(t) = 1$$

if and only if the element associated with this variable is excited.

Learning

Clearly, we can associate a rewarding procedure with many combinations of a stimulus and a response, so that, given the stimulus, the system becomes more likely to produce the response. The simplest rewarding procedure is the transformation $T_1(G^*)$ with $\mathcal{R}$ so defined that

$$\mathcal{R} = 0 \text{ if } \Gamma_m \Delta_l = 0$$
$$\mathcal{R} = \text{a positive value if } \Gamma_m \Delta_l > 0$$

where Γ_m and Δ_l are the selected stimulus and response.

The limits upon what the system can and cannot be persuaded to learn are determined by the kinds of game which are played within it. It is useful to distinguish the two extreme types of learning of which the system is capable.

(1) The response Δ_l is a transient evoked by a unit impulse of stimulus Γ_m and will occur in some but not all, cases, conditional always upon the existence of a stationary state G^*_α, σ_α B_α. Thus Γ_m is a perturbation of G of the type described in Case 5 Upon those occasions when Γ_m evokes Δ_l we suppose that B_α is realized by $A^\#_{\alpha 1} = b_{\alpha 1}$ and on those occasions when Γ_m does not evoke y_l we suppose that B_α is realized by $A^\#_{\alpha 2} = b_{\alpha 2}$. Suppose that $A^\#_{\alpha 1}$ and $A^\#_{\alpha 2}$ have approximately equal maintenance costs, i.e., that $R_{\alpha 1} \approx R_{\alpha 2}$, it will not be difficult to reward the system so that $A^\#_{\alpha 2}$ (which we take to be initially improbable) replaces $A^\#_{\alpha 1}$ (which initially predominates), since $A^\#_{\alpha 1}$ and $A^\#_{\alpha 2}$ are likely to be hybrid forms, so that both exist, but with unequal probabilities. On the other hand, if $A^\#_{\alpha 2}$ is not a hybrid form, its construction cost $r_{\alpha 2}$ must be supplied [1].

Now even when Γ_m does lead to Δ_l, this result is conditional upon the existence of G^*_α, σ_α, B_α. We thus recognize a characteristic akin to " attitude ", in the sense that the performance of a learned skill depends, in man, upon his adopting the appropriate " attitude " towards the world, and in the system, upon its being in a particular stationary state.

(2) The second type of learning concerns the " attitudes " themselves. Over an interval, the system will learn to adopt those " attitudes " which lead to the greatest reward. But we are concerned with the more specific process, namely, given a system in any state, how does a stimulus change the system into the particular stationary state defined by " play the particular game ", or, " adopt the particular attitude, needed in order to evoke a rewarded response ".

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[1] See Diagram 7, *Cybernetica*, Vol. III, n° 4, 1960, p. 293.

In principle we can use the same rewarding procedure, for there is always a positive probability that any of the possible games will be played. However, it is clear that when some structure has been built up, perhaps as a result of previous learning, there will exist a subset of " probable games " and a large number of very " improbable games ". An efficient training procedure must take this into account, and select transformations Z such that one of the " probable games " will be transformed into the " required games ", say G_α^*, σ_α, B_α so that G_α, σ_α, B_α can exist, be rewarded, and thus stabilized reasonably often. Thus the selection of stimuli is no longer arbitrary. We must choose those Γ_m which induce the appropriate Z.

The job of constructing an efficient training procedure is eased by a many to one relation between the game which is played and the possible assertions " Γ_m leads to Δ_l ". Thus, in practice, Γ_m leads to Δ_l, not for a single G_α^*, σ_α, B_α but for a set

$$[G^*_{\alpha_1}, \sigma_{\alpha_1}, B_{\alpha_1} \,;\, G^*_{\alpha_2}, \sigma_{\alpha_2}, B_{\alpha_2} \,;\, \ldots\ldots]$$

where $[\alpha_1, \alpha_2, \ldots]$ are included in α. In general " Γ leads to Δ " is invariant with respect to transformation of the game, or the " attitude ", in much the same way that some of the games or the " attitudes " G_α^*, σ_α, B_α exist in the system, are invariant with respect to transformations of a stimulus pattern. We use the argument of McCulloch and Pitts as a basis for this latter remark after interpreting G_α^*, σ_α, B_α as a statement, both of the activity *within* and the anatomy *of* the terminal mosaic of neurones $\xi \subset \Xi$ which appears in their paper [25].

Just as in the first type of learning, a system with many hybrid forms is at an advantage. Here, of course, we mean hybrid coalition structures, and it is helpful and legitimate to adopt a chemical analogy. Each possible G_α^*, σ_α, B_α corresponds to a stable molecule. It may occur that nearly all molecules are resonant, i.e., that nearly all G_α^*, σ_α, B_α have hybrid coalition structures so that B is representable by a mixture of forms B_1, B_2... (it is important to emphasize the word *represented*, for B *is not* such a mixture). In this case training of the second type amounts to changing the contribution made to the hybrid by some of its components and, in particular, increasing the contribution of one. It is accomplished by rewarding, and thus stabilizing a particular G_α^*, σ_α, B_α. Suppose, however, that G_γ^*, σ_γ, B_γ (which we desire) does not exist. We have two alternatives. In the first place it might be possible to induce the construction G_γ^*, σ_γ, B_γ at a

cost of r_γ. On the other hand it may be that G_α^*, σ_α, B_α and G_β^*, σ_β, B_β exist such that the " reaction "

$$[G_\alpha^*, \sigma_\alpha, B_\alpha] \& [G_\beta^*, \sigma_\beta, B_\beta] \rightarrow [G_\gamma^*, \sigma_\gamma^*, B_\beta]$$

can be induced to take place by applying some " catalytic " sequence of transformations Z. The symbol & has been used to indicate an arbitrary composition rule. Such a sequence is an efficient training routine [7]. The " reaction " is no more nor less than the combination of a pair of stable games into a single game, and the efficient " catalytic " sequence is any modification of the payoff functions such that the combination occurs. Our previous arguments indicate that such a sequence is calculable in specific cases.

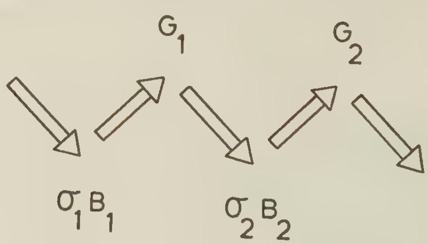
Search process

As described, training involves two processes:

(i) disturbance of the system (either by an external stimulus or as a result of its latent activity) until a desired stationary state G^*, σ, B is reached;

(ii) rewarding of this stationary state, in order to stabilize it (when it is reached).

On the face of it, the process (i) looks like a simple minded, natural variation and (ii) an equally simple minded natural selection, just chance trial and reward. However, from our previous discussions, and bearing in mind that transient conditions between stationary states have the form



it should be clear that the search process, whereby G^*, σ, B is attained, must be evolutionary. The " next step " depends upon the constraints which are imposed because the " previous steps " have occurred. In view of this the coalitions of players have the

status of " demons " in Selfridge's Pandemonium and the restrictions of Ψ stability which apply within our model determine one set of rules that might be used in Pandemonium for replicating " demons " from the bits and pieces of their less successful ancestors [19]. Evolutionary development characteristically occurs in systems which must pay for themselves, i.e., in systems which must be rewarded in order to survive and in which reward supplies the money needed to assemble their parts from raw material [23]. In our own artefacts, nucleation is responsible for the appearance of active elements, as a function of the money available, and these in turn pay for the construction and maintenance of their interconnections. In Pandemonium [29], demons which exist must work for their living.

Decision making

Such a system (which is certainly a self organizing one) has always been regarded as a decision maker, and similarly, the players, or coalitions of players, can be regarded as jockeying for power in determining the outcome. Transformation from the picture of a partly competitive game to decision making image of a legislature is often useful. In particular cases the theory of voting is more tractable than the theory of games (though, strictly speaking, the theory of games in its broadest form includes the theory of voting coalitions). It is possible, for example, to specify the " power " (in the technical sense) of a given coalition and to ascertain which elements are (again in the technical sense) " pivotal " elements. Further, it brings out an important and basic distinction, which separates the decision process in a self organizing system from this process in a finite probabilistic automaton.

Suppose that a decision maker is presented with an undecidable issue. The evidence which it has, combined with its own state, is insufficient to determine one of several alternatives. Maybe, in the simplest case, all of a finite set of alternatives are equally acceptable. Maybe in a more pertinent case, none of the alternatives are appropriate within the logic of the system, or maybe the logic itself is apparently contradicted. For example, a supposedly transitive relation between internal categories may no longer appear transitive. In any of these cases a finite probabilistic automaton throws a dice, and the chance event determines the outcome. We rationalize this design by assuming the first of these patholo-

gies — we assume that the alternatives available to the automaton are sufficient, and that its logic is sufficient and tell it to take the gamblers way out of perplexity.

On the other hand, when a self organizing system is faced with an issue which is, at $t = t_0$ undecidable, no dice is thrown and the concept of chance need not be introduced. Either

(i) if the previous decisions of this system have yielded a monetary payoff sufficient to maintain its structure, with some surplus left over, the system expands until at $t_0 + p\tau$ it is a larger and different system for which the original issue is no longer undecidable, or

(ii) if the system has been unsuccessful in the past, the undecidable issue is an indication it can no longer survive. The system breaks up into parts. These may, later on, be used as building blocks of a more competent system.

Typically, it is impossible in a self organizing system, to say at any instant *where* the decision is made or *what* the majority organs may be [30]. It is, of course, some pivotal coalition but, even in a stationary [24] state, the physical connectivities which mediate a coalition structure are labile. It seems to us that this lability which accounts for (i) and (ii) is essential and characteristic of any system which is a decision maker in the same sense that a man, for example, is said to be a decision maker.

In a slightly different way, the point has been made by McCulloch, who stresses the importance of a " redundancy of potential command " [31] and who is studying its logical expression. It seems to us that his study and ours [32] are complementary for the present approach may elucidate not so much the logic, as the genesis of a " redundancy of potential command " within a decision making artefact.

APPENDIX I

DESCRIPTION OF THE EXPERIMENTAL MECHANISM

The social interaction experiment is realized by an electronic system in which a maximum of eight subjects can participate.

Each subject is provided with a display and control panel on which he has

(i) a meter which, for the i-th subject, reads u_i;
(ii) a multi-position switch for directing offers to players;
(iii) a button for sending an offer in the direction specified by the position of the multi-position switch (ii);
(iv) a multi-position switch for accepting offers from the other players. If this switch is in the j-th position the variable $\eta_{ij} = 1$.
(v) a set of signal lamps indicating to the i-th player from whom he has received an offer. At the i-th player, if lamp j is on, the variable $x_{ji} = 1$.

For each of the n modes associated with a player, there is a delay trigger circuit. Describing the i-th trigger circuit, it may be actuated only if u_i exceeds u_{min}. If so, the circuit is actuated, and remains actuated for an interval τ whenever the i-th player presses his button (iii). Thus the output of this trigger circuit is the binary variable ξ_i and the output, when passed through the multi-position switch (ii) is the binary variable ξ_{ij}.

Money is represented in the system as electrical current, and wealth by electrical potential, measured with respect to an arbitrary O. The monetary distance space M is realized by a set of N = 28 nodes, from which capacitors are returned to O so that charge can accumulate at these points. A subset (of $n = 8$ of these) is assigned to the players so that the meters (i) read the potentials upon these capacitors. The nodes are connected by resistances m_{ij} which are distributed on a plug board and any of the unattached (N—n) nodes can be associated with constant or externally computed potentials to act as sources and sinks of money.

The signal distance space C(t) is simulated by an 8×8 clamp diode and capacitor matrix, each capacitor retaining a charge $c_{ij}(t)$. Each player is assigned one row and one column of this matrix. The i-th column is unclamped by $\xi_i = 1$. In this case

(1) a vector of eight potentials proportional to the eight charges c_{ji} appears at eight row outputs;
(2) if $\xi_{ij} = 1$, a charge proportional to c_e is added to c_{ji};
(3) the charge of all capacitors is reduced by $V_0\, c_{ji}$;
(4) if $\xi_{ij}\, \eta_{ji} = 1$, an additional charge is added to c_{ji}.

The row outputs are amplified and applied to trigger circuits. If the j-th row output exceeds a limit c^* the j-th trigger circuit is energized. If so, $x_j = 1$, if not $x_j = 0$.

The profit condition of an offer, made by one player, being accepted by the player to whom it is made, is extracted by relay coincidence circuits in which one of a pair of relays is energized by the column, or offer making delay trigger circuit, and the other relay in the pair by the row trigger circuit. These switch a contact network which also includes the acceptance switch and through which the capacitor on the i-th node is charged from a constant potential, via a resistance R, if the i-th players offer is accepted. The resistances are, in fact, separated for each possible offer and the R_{ii} are made less than the R_{ij}, so that the profit, which goes with acceptance of one's own offer is less than the profit which accrues if your offer is directed to, and accepted by, another player. A separate contact network on the same relays switches the signal lamps.

MODES OF CONNECTION AND EXPERIMENTAL SYSTEMS

Although the mechanical system provides for any trading between eight players, certain restrictions have been imposed upon it for the initial experiments. Two restricted modes of connection will be described.

In both of these modes the players are partitioned into two disjoint subsets I and II. In mode 1, players 1, 2, 3, 4, in I may only communicate with (receive offers from and send offers to and receive signals about) players in the subset I. A similar comment applies to players 5, 6, 7, 8, in II. In mode 2, players 1, 2, 3, 4, in I may only communicate with players 5, 6, 7, 8, in II and players in II with those in I. The purchasing and directing switches in each control board are thus limited to four active positions for each player, and the 8×8 clamp diode capacitor is reduced to two 4×4 matrices.

These restrictions are conveniently expressed in terms of the matrices $A(t)$. Let (A) be a square submatrix of $A(t)$ and (O) be a matrix with all entries O. In mode 1, the form of $A(t)$ will always be like

$$\left.\begin{matrix} (A) & (O) \\ (O) & (A) \end{matrix}\right\} = F_1$$

whatever the particular values of the a_{ij}. In the case of mode 2 it will be like

$$\left.\begin{matrix} (O) & (A) \\ (A) & (O) \end{matrix}\right\} = F_2$$

Thus F_1, F_2, are subsets of the set of all matrices $A(t)$. Experimental systems are obtained by combining these constraints upon the signal connectivity, with constraints upon the currency distribution (corresponding to different values of m_{ij} in the network).

ACTUAL ROUTINES

Since our intentions will be apparent from the discussion in the paper, we shall outline the proposed experiments very briefly. Apart from initial runs in which only four players (half the system) will be used, the immediate experimental program deals with the conditions obtained by combining each of S_1, S_2, S_3, S_4, with each of F_1 and F_2. For each of these eight conditions we wish to discover the effect of varying w_1 and c_e when the system has reached a stationary state.

Facilities are provided, in the system, for computing a measure $\mathcal{M}$ of the activity of the players and it is also possible (due to the restrictions described above) to have a pair of components w_{I} and w_{II} in place of w_1 and a pair of components c_{I} and c_{II} in place of c_e. We shall thus investigate conditions such as

$$\begin{array}{ll} w_{\mathrm{I}} = \text{constant} & w_{\mathrm{II}} = \text{constant} \\ c_{\mathrm{I}} = \text{constant} & c_{\mathrm{II}} = \text{function of } \mathcal{M} \end{array}$$

$$\begin{array}{ll} c_{\mathrm{I}} = \text{constant} & c_{\mathrm{II}} = \text{constant} \\ w_{\mathrm{I}} = \text{constant} & w_{\mathrm{II}} = \text{function of } \mathcal{M} \end{array}$$

which have obvious practical importance in connection with self organizing systems. Further, we propose to investigate what happens when the source potential is made proportional to $\mathcal{M}$ or to some external computed function of the activity in the system, because this kind of feedback is relevant to rewarding the behavior of a self organizing system. Finally

(1) We intend to examine the effect of supplying the players with information about the payoff function, either by giving each player eight meters in place of one, or, as proposed by C.E. Osgood, circulating data about the payoff function in a bulletin. At first sight the latter expedient seems more interesting.

(2) We intend to test the subject — using aptitude and personality tests — and to see what occurs, if special persons are given special positions in the system.

RECORDING MECHANISM

The system is adequately described by 8 binary variables x_i and further 8 binary variables ξ_j together with n analogue variables describing potential at nodes in the currency network. All of these measurements must be made at discrete intervals t, $t + 1\tau + 2\tau + 3\tau + \ldots$ not greater than the interval between any pair of offers.

The binary variables appear on a set of signal lamps mounted above an oscilloscope. A sampling mechanism has been constructed to sample any 24 nodes in the currency network and to represent the potentials u_i as vertical deflections along a horizontal coordinate representing the node being sampled. This analogue display appears on an oscilloscope, the sampling interval for 24 nodes being about 1 second, which is less than the expected offer rate. The oscilloscope, the set of 8, x_i and 8, ξ_j signal lamps, and an indication of t, will be photographed either at regular intervals or whenever an offer is made.

PHYSICAL DATA

The mechanism has been constructed by Messrs. Gene and John Gunsalus and is housed, together with its power supplies, in a six foot rack. In addition to the rack which is moveable on wheels to an experimental location, there are eight boards for the decision makers on 50 foot cables and the recorder and oscilloscope.

APPENDIX II

Thread structures are typical realizations of these self organizing systems. As these have been discussed previously we only make reference (to previous reports of NONR 1834/21 and to [7] and [14]). The systems described have a fixed M but not usually a fixed n. Recently a system has been developed (chiefly by Mr. A. Addison in this laboratory) in which M is varied as a function of the activity of the system. This system is developed, in the simplest case, if a pair of electrodes — say a ring electrode — and a central point electrode are immersed in a solution of stannous chloride in octyl alcohol. A set of tin fibrils ramify from the central electrode. These continually bifurcate and reform. At each bifurcation there occurs an unstable " discharge region " which acts as an

amplifier. Thus a thread is like a " string of beads ", the beads being tin crystals, and the string, the amplifiers. In such a system we can regard the initial M as homogeneous and determining a concentric field distribution between the electrodes. Later, this homogeneity gives place to an elaborate pattern induced by all the ramifying threads. On the other hand, signal connectivity between amplifiers is confined to a particular thread.

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The human side of automation

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Science and technology seem destined to be among the primary determinants of the events of the second half of the twentieth century. Science is knowledge, systematized and formulated to discover general truths. Technology is science applied to the industrial arts. Science is concerned with understanding ; technology is concerned with practical uses, and one of the most significant technological developments in history is automation. Its countless uses in industry promise undreamed of benefits, but in its total impact lurk some hidden dangers. As an old saying puts it, one cannot bask in the morning sun of a new day without leaving a shadow behind.

Automation is more than a technology. It is a philosophy of manufacturing, requiring that the entire productive process, from raw material to final product, be analyzed so that every operation contributes most efficiently to the achievement of the goals of the enterprise. Automation is an outgrowth of a threestage process of technological development that is over two hundred years old. The first stage was mechanization, a technology based on forms and applications of power. The second stage was mass production, a technology based on principles of production organization. The third is automation, a technology based on communication and control. With the advent of automation, the function of industry has become, in the words of Dr. Vannevar Bush, " the planned application of scientific results in an economic manner for the increase of man's physical wellbeing (1) ".

(1) *Automation and Technological Change,* Hearings before Subcommittee to Economic Stabilization, Pursuant to sec. 5 (a) of Public law 304, 79th Cong. ; 84th Cong., lst sess., Oct. 14-28, 1955 (Washington : U.S. Gov't Printing Office, 1956), p. 615.

Reasons for automating

Sometimes a firm goes in for automation like a young man getting married. He knows he can't justify the step on economic grounds, but he just can't resist the temptation. Some ventures into automation are probably traceable to executive egos, public relations sensitivity, or engineers'relish for new heights of mechanical complexity. The glamour attached to having the fanciest plants or the most intricate machinery has, no doubt, led to some enormous expenditures that may well go down in history to what Veblen would have called " conspicuous investment ".

The ultimate test of business success is profit, however, and probably most automation has an underlying economic motivation. First, automation can perform many tasks that cannot be accomplished without it. For example, only electronic computers can make the millions of calculations needed for guiding a rocket ; humans could never do the staggering amount of arithmetic in time for the results to be useful. Work never before possible can be done with automation.

Because of their speed of operation, for example, automatic transfer machines, electronic computers, and other automation equipment can perform some tasks that would otherwise be impossible, no matter how much power was used or how well the work was organized and managed. Manipulating an atomic pile or controlling rapid chemical reactions could not be done without automation. Some new products, like polyethylene, a soft but strong plastic used for making thousands of items today, could not have been produced without automation. Nor would color television be possible, since no human being could ever put the hundreds of thousands of colored dots in their right places in the tubes without automatic control machinery. Automatic sensing devices can operate under conditions deadly to man — in intense heat, in bitter cold, in poisonous gases, in areas of atomic radiation.

A second reason for using automatic machinery is to save labor costs on jobs that are already being performed without automation. Utility and insurance company officials report that each electronic computer can now replace 170 to 200 persons. The Ford Motor Company has indicated that automation has reduced labor costs by 25 per cent. Needless to say, the impact on both management and labor from such technological improvements is enormous.

Effects on commerce

A few years ago, management and administrative staff comprised only a small part of total labor costs ; today, in a typical large enterprise, they receive half of the wage bill. A major problem facing management and the nation is the rising tide of red tape. Due to a mushrooming of business and government bureaucracy, there has been an alarming growth of paper work in recent years ; the present volume of office activity is astronomical. Thirteen billion checks worth $ 2 1/4 trillion were written in the United States in 1958, and the American Bankers Association expects this to grow to 20 billion cheks by 1963.

Automation promises to reverse this trend. The greatest non-manufacturing potentiality for automation is in the communication, storage, and manipulation of information. Automation of check-handling is now facilitated in many of the larger banks by magnetic ink imprinted on checks and read by automatic sorting machines. One of these machines can sort 750 cheks per minute, saving from 25 to 40 per cent of the bookkeeping departement's time. Automation is capable of radically altering both the productive and administrative processes of the business firm, and the best proof of this is found in the offices where the need is greatest.

Office automation has two main effects. First, it takes over some existing clerical jobs and, second, it performs new tasks not feasible by manual methods or with more primitive machines. When first installed, computers usually perform only routine functions such as work scheduling, inventory control, billing, payrolls, and cost accounting. But electronic computers and related equipment have applications far beyond office routines. They are able to integrate either a conventional or an automatic factory operation with the office system that controls it. Although there is a considerable amount of automation in factory production there is much more in office work. An integration of the two would seem to be the next logical step. When this occurs, there are bound to be far-reaching effects on top management itself. The more spectacular uses, such as providing all kinds of special reports and long-range planning, will, of course, have to develop through experience. Only then will the computer really become a fundamental management tool.

In both theory and practice, automatic data-processing by electronic computers has many commercial uses. The most promising are inventory record-keeping, billing, and payroll book-

keeping. In a large number of instances, machines now in use can perform their tasks for less than the present clerical cost. For example, computers that will keep track of several thousand items of inventory can be acquired at a cost of about $ 20,000 a year, which is less than the clerical salaries saved exclusive of overhead. It is already common in large firms for centrally located computers to receive, by the close of the day and via telegraph, output figures from each department or daily sales data from far-flung branches. When the manager gets to work the next morning, a complete summary of the previous day's operations is on his desk.

This new timely information permits "management by exception". This means that normal performance standards concerning such problems as labor costs of each product or operation, materials costs, sales quotas, and so on, are set for all clerical, sales, and operative personnel. The electronic computer automatically processes all data and information from these departments, and the results are then compared with the established standards. Management need be concerned only with those instances where the standards are not being met. This is one way in which automation can take over the huge burden of routine administration and leave executives free to do what they are supposed to do — make decisions involving judgment, something a machine can never do.

Lethargy, traditional thinking, and lack of information are usually more important deterrents to installation of automation than technological or economic barriers. To help firms avert these problems, private, cooperative, or state computer centers and other automation service organizations have been established. These newly formed organizations are not bound by company tradition or limited by individuals in a firm's management who might otherwise deter change or progress. They can specialize in automatic data-processing, and can attract expert staffs and make them available to clients without committing these clients to heavy initial outlays or long-run expenses. Because of the important functions that these firms perform, they should continue to expand rapidly.

Effects on management

Machines work better.

There are several appealing features of automation that should ease management tensions. First, automatic machines can frequently work better, faster, and more safely than people and can do

many things people cannot do. As previously mentioned, they can operate under conditions that preclude human endeavor. They do not experience fatigue or monotony and are frequently more dependable than humans, making fewer mistakes, never forgetting, and requiring no retraining. In other words, technological advancement can often be liberated from the limitations of human labor and control, enabling the management and labor of industry to accomplish much more. On the other hand, although computers can make simple decisions between two clearcut alternatives, they cannot exercise the kind of judgment that is inherent in management fuctions. Automation can be an aid to, but never a substitute for managerial responsibility.

Machines aid control.

A second effect of automation on management arises from the continuous nature of production. If used intelligently, automation definitely can increase the effectiveness of managerial control. It can reduce the number of clerical staff members and the physical volume of paper. This alone facilitates control. Electronic computers can also permit more rapid and efficient disposition of the irreductible minimum of office work necessary for controlling a large and complex industrial, commercial, or governmental operation. The speed and accuracy with which information can be processed increase both the span and intensity of control.

While requiring greater control, automation also permits greater control. Electronic computers increase the amount of knowledge, the accuracy of information, and the speed with which it is obtainable — thus giving management a much clear picture of over-all operations. Knowledge of the consequences of alternative courses of action becomes readily available, and business operations in the future can be conducted more rationally. Unprofitable product operations can be more quickly discovered and eliminated ; credit managers will be able to follow the changes in financial ratios day by day. Collective bargaining and product-pricing can be based on more accurate information, so that areas of controversy will be narrowed and conflicts based on misunderstandings of facts will decline.

Business in all its phases is rapidly becoming more complex, and managers can expect to have much more difficulty keeping over everything. The quality of management must change in degree *and* in kind. Even though a large portion of their former burden will be taken away because of the use of self-regulating

automatic equipment, a much higher level of technical proficiency will be required of all management people.

Machines demand new skills.

A third effect of automation follows directly from the second. Lower-level supervisors will need to develop new skills in handling subordinates who are highly trained technically and perhaps highly strung emotionally. As more expensive equipment is entrusted to them and their responsibility is augmented, supervisors will also need a deeper knowledge and appreciation of technical productive processes. For example, rapid change-over times and greatly decreased inventories require that supervisors have more technical knowledge than ever before.

These supervisors also need to pay more attention to nontechnical matters such as the worker's feeling and group relationships. The supervisor must recognize that it is irrational to expect workers always to act rationally. Many " old-time " foremen still think of productivity as the direct result of physical activity, as it was in the nineteenth-century sweat shops. These old-timers do not understand how men can be standing around talking or listening to music while automatic equipment roars out production. Yet this kind of situation is often essential to the highest productivity in automated factories. The pressure on the seemingly relaxed and idle machine-tenders may be greater than ever. Their responsibilities and accompanying anxieties have increased although their physical activity has declined.

Furthermore, whereas the workers in many old-style factories were dirty while the supervisors were clean, automation frequently erases this distinction. Nonmonetary symbols of status and position, such as cleanliness, dress, working conditions, and privileges are often more important than money for job satisfaction and incentives. If physical appearance does not permit the casual visitor to differentiate labor and management or different levels of personnel within labor management, then new symbols of status will have to be devised to maintain organization, dignity, and adequate incentives.

Some companies have experienced a considerable broadening of the span of control as a result of automating their plants. However, a fairly serious shortage of capable shop foremen and other supervisors remains. " Job enlargement ", a reversal of the long trend toward specialization, seems to be indicated for many management a well as labor functions.

Machines require broader knowledge.

A fourth effect of automation, and a corollary of the third, is that it accelerates the need for broader knowledge in higher levels of management. Two factors have continued to retard the evaluation of business organization and management required by automation — tradition and the unending search for pat answers or easy solutions to complex problems. Management structure has too often developed separately from technology in manufacturing, and, as one vice-president in charge of manufacturing puts it, " there is a heavy brick wall between the two ". Automation puts a high premium on ability to adjust, and big enterprises have their share of people at all levels who resist change. The prime requisite of a successful executive or manager is the ability to adjust to new conditions quickly. In fact, management should be the first to recognize and accept necessary changes. Unfortunately, under conditions of rapid change, some management people may be so absorbed with the impact of the change on themselves that they readily believe they do not have time to practice principles of economics and human relations. It may be difficult for some executives to keep in mind their real function. It is easy to confuse the means with the end, to become obsessed with the methods themselves.

Conservatism was once the basis of sound management philosophy, and firms could expect continuous growth or at least a comfortable existence using tradition, experience, and guesswork as guides. These tools are now greatly outmoded. Over half a century ago, the United States Electric Light Company exiled its guiding spirit, Hiram Maxim, to England on a $ 20,000 annual life pension because his free-thinking mind was producing inventions at such a rate that equipment was being rendered obsolete before it was paid for. In England, Maxim made some of his greatest inventions, and while he was being knighted for his great accomplishments, the firm that banished him was going out of business.

Today no responsible business executive would think of doing such a thing as this ; yet some managements are still not prepared, either in education or attitudes, for the age of automation. They sometimes are unaware of the importance of their position, authority, and responsibility.

Automation creates a steady, endless flow of data that in itself tends to break down departemental and divisional lines and hence, in receptive minds at least, to broaden management thinking and destroy some intellectual provincialism. Today the firm without an

alert, eager, research-conscious, and farsighted management is courting disaster. Yet some managements still seek monopolies, tariffs, and other special protections to avoid facing the future with courage and imagination. Although generally there has been a great awakening among managements in recent years, there is still a need for thawing some frozen attitudes.

Machines alter basic philosophies.

Fifth, automation affects the philosophy and therefore the organization of business systems. In the past many factories were little more than haphazard accumulations of machines. Automation, however, tends to make the entire factory into a single supermachine. Furthermore, office operations (which are frequently the largest part of an enterprise) have to be integrated within the factory in much the same way as the parts of a single machine are related to each other. The principles of machinery become applicable to the whole business enterprise, and everyone — the company's president, machine operators, and outside salesmen — becomes an integral part of the machines.

With the development of automation in an individual plant, a complete re-evaluation of management functions is frequently necessary to keep a plant operating at top capacity. Often the greatest economies of automation can be attained only if the system of organization and procedure is changed to fit the capabilities of the equipment. Thus, machinery should not necessarily be designed to perform tasks already being done, but the whole body of tasks may have to be altered to make the best use of the machines.

Staff management and staff organizational needs will undoubtedly increase considerably. It may become necessary to change from the traditional line-and-staff organization to a functional organization. As productive processes and factory layouts are changed, the problem of determining managerial responsibility changes. Fuctions that were once discontinuous and specialized are frequently tied together in a continuous flow process. In other cases the improved communications system has made responsibility easier to define and " passing the buck " more difficult for department heads. The specialists needed for automated plants will require more direct control over their operations. Production planning and control will be simplified to the extent that " flow " control and continuous processing replace the intermittent or " batch " type of manufacturing. However, there will probably be

a need for tighter control and the instant dispatching of repair crews when trouble develops in the automation process.

Automation elevates long-range planning, co-ordination, and control to major importance and emphasizes the need for management to think less in terms of individuals and particular problems and more in terms of groups and over-all requirements. In his recent pioneering investigation of thirteen automated plants, Professor Bright found that " the outstanding conclusion of this study is that automation puts a great premium on managerial planning (1) ". There must be long-range planning for product development, materials procurement, manufacturing and marketing. The automated plant is highly integrated throughout. This integration, plus the need for continuous operation already explained, greatly increases the vulnerability of the plant to breakdowns and other interruptions. Preventive maintenance becomes necessary, and administrative breakdowns become as costly as mechanical ones. Relations with labor suppliers, and customers take on added significance.

Where management has failed to fully understand automation and predict its impact, the results have been costly. John Diebold claims businessmen have done very little hard thinking about what automation can do for them, although they have been fascinated by the equipment itself. Diebold says that they have spent millions of dollars for new, automatic equipment that is doing no more than the old equipment was doing more easily and economically. He tells of a body frame manufacturing firm that wanted to automate its assembly line. It purchased equipment from different suppliers without proper co-ordination. The machines didn't work properly, so manual operations had to be set up parallel to the automated ones. Ultimately, the entire facility was shut down with a resulting loss of $ 10 millions (2).

In another case a utility company spent four years preparing for a computer that was expected to do a certain job in twenty hours. When the equipment was installed, the job took sixty hours and the machine had to be returned. These fiascos result, says Diebold, because most management thinking about automation " has already become rigid and cluttered with stereotypes that stand in the way

(1) James R. Bright, *Automation and Management*. Harvard University Press, Cambridge, Mass., 1958, p. 12.

(2) John Diebold, *Automation: its Impact on Business and Labor*. Pamphlet N° 106, National Planning Ass'n, Washington, 1959, p. 4.

of real progress ". In fact, Diebold claims that automation's impact is in some cases the opposite of what management expected.

Furthermore, management has not only been fascinated but intimidated by the extreme complexity of machinery. It has allowed technicians to take over the whole operation of the machines as well as the management decisions as to how they are to be used. " Electronics committees " have been appointed that do little more than give the impression that something is being done. Businessmen overestimate the specialized knowledge of engineers and regard it with awe, while engineers frequently underestimate the complexity of business operations and consider them something to be mastered in a few months. Yet, as Glenn White of the Chrysler Corporation says, " Somebody who has a good knowledge of how to run your business ... can be trained in electronics much easier than somebody who knows electronics can be trained in how to run your business". Perhaps this was best summed up by a recent New Yorker cartoon, which depicted a wife saying to her dignified but worried husband, " I can't understand why you keep fretting, John. Automation or no automation, there will always be a Chairman of the Board."

Effects on labor

When Frederick Taylor led his crusade for " scientific management " in 1895, he proclaimed the primacy of piecework, asserting that the business entreprise and everything in it (including human minds and behavior) , could be broken down into tiny bits and pieces and analysed in the same fashion that chemists analyze an unknown substance. Following Adam Smith's theory of specialization and the division of labor, Taylor extended his " scientific " analysis from production to every other aspect of business. He sought to reduce work to its simplest elements in order to rationalize these elements and thereby increase workers' output. For example, he made a careful time-and-motion study of every movement involved in the job of handling pig iron. By theoretical analysis, Taylor devised a more efficient method and taught this method to a workman named Schmidt who was soon able to handle 47 tons of pig iron a day as opposed to 12 1/2 tons previously. Furthermore, says Taylor, Schmidt was " glad to do it ".

Implicit in Taylor's theory, however, was the assumption that men could be studied and treated like machines. Taylor realized that this mechanical regime would have some kind of impact on

workers. Consequently, he suggested that the worker most likely to succeed would need to be stupid, phlegmatic, and resemble an ox.

Fortunately, workers refused to submit completely to machines and let the logic of efficiency take away all their judgment. Unfortunately, workers all too often had to express their revolt against machinery and rationalization by using their individuality and ingenuity to outwit the industrial engineer rather than by cooperating with management to their mutual advantage.

Improved working conditions.

In contrast to mechanization, automation seems to improve working conditions in several ways. First, there is nearly always greater safety because of mechanized materials-handling, elimination of the most hazardous jobs, and reduction of the number of people in direct production areas through the use of remote controls. Hernia, eye troubles, and foot accidents have virtually disappeared in the Ford Motor Company's automated Cleveland engine plant. In one major automotive stamping plant, scrap steel formely was collected at individual scrap collection areas where it was baled and moved on open conveyors to the central collection area. Workmen were exposed to physical dangers, and there were frequent injuries. Automatic equipment now loads the scrap into balers, and closed conveyors move it to the collection area where it is automatically loaded. The whole process is monitored by television.

In the pottery industry, silica dust has long been a hazard. Closed silos and automatic conveyors now handle all dust-producing materials. In the chemical and petroleum-refining industries, potential toxic exposures were always a great risk. Automation has reduced this risk but has added a less likely although more dangerous risk — a rupture in the lines could lead to a single, catastrophic exposure. In one plant, several operations were combined in one location by automation, and a serious fire occurred two weeks after the change-over. While automation may practically eliminate many types of accidents and industrial diseases, the risk of isolated but disastrous accidents still exists and, in a few rare instances, the dangers are actually increased.

Increased emotional hazards.

The decline of physical risks through automation could be partially offset by greater emotional hazards. The highest incidence of gastric ulcers in the hourly paid group is now among skilled machi-

nists who exert less physical effort than most workers. Ulcers, although physical in results, are caused primarily by mental or emotional stress. It has also been estimated that 20 per cent of all employees in peacetime are borderline emotional cases. A recent study of heart diseases revealed that unskilled laborers are among the least likely to have heart attacks of all occupational groups, while among those most susceptible are people working with computing machines.

Automation may increase workers' feelings of security because the continuous nature of automatic processes permits greater regularity of employment and, therefore, increased job security. On the other hand, this advantage can be partially offset if regularity of employment means regularity of nightwork, or if automation causes boredom or leads to a more rigorous industrial discipline from machines. Automation may reduce the interaction among workers both by reducing their numbers and increasing the distances betweem their work places. A study of workers' attitudes toward automation by Professor W. A. Faunce of Michigan State University showed that the main complaints of 125 workers were increased noise, need for closer attention to work, and most important loneliness caused by being isolated from other workers (1). At least one British union has already asked for " lonesome pay ".

Related to lonesomeness is boredom. This is not peculiar to automation, of course. It is perhaps more typical of old-style conventional mechanization than of automation, but some operative jobs under automation may still be highly routine and boring. These jobs are usually the most likely to be mechanized or automated, however, since they are based on simple, repetitive tasks. In Coca-Cola bottling plants, the old method of inspection was to put four bottles of the finished product in front of a strong light and have an inspector watch for any foreign matter in the drink. Then someone initiated a conveyor system in which the bottles ran continuously. This was a much faster process, but the job was so boring that every now and then a 7-Up had to be run through to see if the operator was alert.

The skills required.

Automation may have improved working conditions generally

(1) William A. Faunce, Automation in the Automobile Industry : Some Consequences for In-Plant Social Structure, *American Sociological Review*, XXIII, August, 1958, pp. 401-7.

but, contrary to popular opinion, it does not seem to have upgraded workers very much. A recent survey of a cross section of metal-working firms that had recently automated revealed that 43 per cent of the firms believed the new machinery required less skill than the old equipment, 30 per cent reported no change in skill requirements, and only 27 per cent felt that higher skills were required (1).

Professors Mann and Williams of the University of Michigan studied a plant that, prior to automation, had 450 employees performing 140 different tasks in its central accounting area. They estimated that 50 per cent of the tasks were eliminated by automation and 30 per cent more were substantially changed. Ninety per cent of the workers were directly affected. But with all this dislocation, there was no significant upgrading in skills required. Before automation, the classification range of jobs had been from 3 to 13, with an average job grade of 8.0. After automation, the average rose almost imperceptibly to between 8.1 and 8.2. Even some of the highest-grade and supervisory tasks were progammed for the computer (2).

Several studies indicate that automation does not even increase the maintenance force significantly except during the " debugging " period and for electrical maintenance. Newly automated plants frequently hire inexperienced workers and give them only limited training. Some case studies show that former machine operators tend, after automation, to become only machine monitors. They rarely have to actually *do* anything, but they must be constantly alert. Other evidence points to job enlargement, but this is often in the form of a requirement that the operator be responsible for more complicated machinery or for a greater variety of machinery.

Even operating a variety of machines need not require greater skill. A study of a large utility company in the United States revealed some job enlargement from automation as do some other single-plant studies, but a mere requirement of familiarity with more different kinds of equipment is not the same as upgrading. Nor do more complicated machines necessarily require more complicated skills to ted them.

A large aircraft manufacturer made a theoretical job analysis to determine the alibities required of operators of its electronic com-

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(1) *American Machinist*, October, 1957.

(2) Floyd C. Mann and Lawrence K. Williams, Organizational Impact of White Collar Automation, a paper presented to the Industrial Relations Research Association, Chicago, December 28, 1958.

puting equipment. The study indicated a paradoxical combination of high technical competence and low mental capacity — the employee should have a B. S. degree in engineering and an I. Q. of 81 ! As Professor Killingsworth of Michigan State points out, " merely pushing buttons and watching for warning lights is unlikely to hold intrinsic interest and challenge for very long (1) ".

Technological unemployment.

If automation is to benefit labor, it will have to be largely through its effect on the national economy and not through its impact on the plant. Physical working conditions are undoubtedly improved, but there is no other definitely established benefit to workers. Labor requirements in direct production jobs have been substantially reduced, although there have been few layoffs that can be directly attributed to automation. Permanent reductions in the work force due to technological changes are apparently sometimes postponed until a general economic downturn permits layoffs to be blamed on national or international conditions. Then when recovery occurs, fewer are recalled than were laid off. This is part of the explanation why unemployment has remained so high since the 1957-58 recession. For example, there are about 160, 000 unemployed in Detroit who will probably never go back to making automobiles, partly because the industry is past its peak of growth and partly because automation has taken their jobs. Steelworkers returning after the recession found the same work being done by 20 per cent fewer men. Possibly half of the nation's 400, 000 soft coal miners may have to leave industry for good.

Some large employers have admitted publicly that they timed layoffs to coincide with periods of recession when general business conditions could be blamed, even though increased efficiency from automation was the underlying cause of employee reductions. When the upturn came in late 1958 and early 1959, they anticipated further investment in automation and were therefore cautious about rehiring. A top business executive recently said, " I'd rather have our employees work a longer week and pay overtime than add more man than necessary to the payroll. ... It's cheaper to pay the extra expense of overtime than to pay the extra expense of a public relations drive to explain a layoff ".

The employee most directly affected by this type of technological

(1) Charles C. KILLINGSWORTH, Automation in Manufacturing, a paper presented to the Industrial Relations Research Association, Chicago, December 28, 1958.

unemployment is not the one who is fired but the one who is never hired in the first place. As job opportunities have declined in manufacturing, there have been many new openings in the service industries, but the continuation of these opportunities is due more to forces determining national economic growth than to developments within the firm such as automation.

For the most part, over-all economic growth will probably have to provide the economic environment in which new entrants to the work force and the other victims of "silent firing" (such as job transfers) will be able to find opportunities for employment. The obvious and highly publicized advantages of automation for management should not be allowed to overshadow the plight of the little man searching for a place in a growing economy.

IMPRIMERIE DES ÉDITIONS J. DUCULOT, S. A., GEMBLOUX (*Imprimé en Belgique*).